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# Hot Water Deicing of Aircraft

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Final Report



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16. Abstract

A research program was undertaken to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

Results from several previous related studies were used to determine an approach to current testing and as sources of related data.

Tests on flat plates were conducted at the National Research Council Canada (NRC), Climatic Engineering Facility (CEF) in Ottawa. Test parameters included temperature, wind, active precipitation (type and rate), and substrate material. (Standard test plates were fabricated from typical aircraft composite materials as well as from aircraft aluminum.) A controlled level of contamination was allowed to collect on the plates prior to each test run by exposing the plate to precipitation for a predetermined time interval. The resulting layer of ice contamination was then removed by spraying as much fluid as was required to produce a clean plate. Fluids tested included water, diluted Society of Automotive Engineers (SAE) Type I fluid, and full strength SAE Type I fluid.

The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least 3 minutes was the key indicator of acceptable temperature and wind limits.

Laboratory testing has shown that at a precipitation rate of 25 gm/cm$^2$/hr, hot water provides a period of protection equal to or better than Type I mixed to the approved buffer (-3°C) at outside air temperature (OAT) down to -6°C and wind speeds to 10 kph. A Type I premix provided about the same period of protection at the same test conditions (2 to 3 minutes). Increasing the level of surface contamination has no significant effect on fluid performance since increased quantities of hot water are required to deice, which negates the effect of increased contamination. A 3-minute window before the onset of freezing, using hot water in quantities greater than what is required to deice, is attainable down to an OAT of -9°C with wind up to 10 kph on aluminum surfaces.

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# PREFACE

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# EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration (FAA), APS Aviation has undertaken a research program to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

Hot water has been authorized and used as an aircraft ground-deicing agent for many years. Its use offers significant benefits to the operator, primarily reduced impact on the environment and reduced operating costs. Despite these potential benefits, hot water is not used as commonly as it had been in the past. One reason is its restrictive temperature limitation.

In the past, when hot water deicing enjoyed greater popularity, the allowed temperature range was greater than that now authorized. Consequently, the procedure was applied to a greater segment of the deicing operation.

The standard method for deicing with hot water involves removal of the contaminant with a hot water spray having a temperature at the nozzle of at least 60°C, followed by an over-spray of anti-icing fluid. The Society of Automotive Engineers (SAE) Aerospace Recommended Practice ARP4737 that defines this methodology states that the anti-icing fluid is to be applied before the first-step fluid freezes, typically within 3 minutes. It also establishes limitations on ambient weather conditions for use of hot water as a first-step fluid, wherein the outside air temperature (OAT) must be no lower than -3°C. There is no reference to wind as a limiting factor.

The intent of this OAT limitation is to provide to the deicing operator a minimum 3-minute window for application of the second-step or anti-icing fluid before freezing occurs. In operational practice, the spray operator must monitor progress to ensure that no surface area refreezes before the anti-icing fluid is applied. As no freeze point depressant is present when water is used as a first-step fluid, the delay in refreezing is due only to the heat that has been transferred to the aircraft surface from the hot water.

Previous related studies include *Hot Water Deicing Trials for the 1994-1995 Winter,* TP 12653E, and a study carried out during the winter 1997-98 season, *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing,* TP 13315E. Further investigation of deicing only fluid application was conducted during the 1998-1999 winter season. Results from these studies were used to determine a current testing approach and were also used as sources of related data.

Tests on flat plates were conducted at the National Research Council Canada (NRC), Climatic Engineering Facility (CEF) in Ottawa. Test parameters included temperature, wind, active precipitation, and substrate materials. Standard test plates were fabricated from typical aircraft composite materials as well as from aircraft aluminum. Because heat transfer to the test surface was a key element of the study, the thermal effect that accompanies removal of a surface contaminant was also examined. A controlled contamination level was allowed to collect on the plates prior to each test by exposing the plate to precipitation for a predetermined time interval. The resulting layer of ice contamination was then removed by spraying as much fluid as was

required to produce a clean plate. Additionally, the effect of applying more hot water than was required to produce a clean surface, was investigated.

The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least 3 minutes was the key indicator of acceptable temperature and wind limits.

Laboratory testing has shown that at a precipitation rate of 25 $gm/cm^2/hr$, hot water provides a period of protection equal to or better than Type I mixed to the approved buffer (-3°C) at OAT down to -6°C and wind speeds to 10 kph. A Type I premix provided about the same period of protection at the same test conditions (2 to 3 minutes). Increasing the level of surface contamination has no significant effect on fluid performance since increased quantities of hot water are required to deice, which negates the effect of increased contamination. A 3-minute window before the onset of freezing, using hot water in quantities greater than what is required to deice, is attainable down to an OAT of -9°C with wind up to 10 kph on aluminum surfaces.

# 1. INTRODUCTION.

At the request of the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration (FAA), APS Aviation undertook a research program to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

## 1.1 BACKGROUND.

Hot water has been authorized and used as a ground-deicing agent for aircraft for many years. Its use offers significant benefits to the operator, which includes reduced impact on the environment and reduced operating costs. Despite these potential benefits, hot water is not used as commonly as it had been in the past.

At least one reason for the lack of use is the narrowness of the temperature range under which hot water is approved for use as a deicing agent. The use of hot water for deicing requires maintenance of strict management disciplines in the deicing operation, and support of these disciplines inherently implies an increase in operating cost overhead (increased training, supervision, etc.). Pragmatically, only when the benefits far outweigh the additional overhead costs and increased complexities in the operation will operators choose to implement hot water deicing.

In the past, when hot water deicing enjoyed greater popularity, the allowed temperature range was greater than that now authorized. Consequently, the procedure applied to a greater segment of the deicing operation.

The standard method for deicing with hot water involves removal of the contaminant with a hot water spray having a temperature at the nozzle of at least 60°C, followed by an over-spray of anti-icing fluid. The Society of Automotive Engineers (SAE) Aerospace Recommended Practice ARP4737 [1] that defines this methodology, states that the anti-icing fluid is to be applied before the first-step fluid freezes, typically within 3 minutes. It also establishes limitations on ambient weather conditions for use of hot water as a first-step fluid, wherein the current outside air temperature (OAT) must be no lower than -3°C. There is no reference to wind as a limiting factor.

The intent of this OAT limitation is to provide a minimum 3-minute window to the deicing operator. The 3-minute window allows the application of the second-step or anti-icing fluid before freezing occurs. In operational practice, the spray operator must monitor his own progress to ensure that no surface area refreezes before the anti-icing fluid is applied.

As there is no freeze point depressant in pure water, the delay in refreezing is due only to the heat that has been transferred to the aircraft surface from the hot water. In the past when hot water was used more widely and before the advent of the modern SAE Type IV fluids, the follow-on anti-icing spray generally consisted of a heated Type I fluid. In current day operations, Type IV fluids are applied unheated. This change in operational environment is an important topical consideration as a heated second-step fluid could be viewed to serve a natural corrective function for any early freezing of the water application not noted by the operator.

Previous related studies include Hot Water Deicing Trials for the 1994-1995 Winter TP 12653E [2] and a study during the Winter 1997-98 season Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing TP 13315E [3]. Further investigation of the deicing only application was conducted during the 1998-1999 winter season. Results from both of these studies are valuable for determining an approach to current testing, and as sources of related data for the subject.

## 1.2 OBJECTIVE.

The objective of this project was to evaluate environmental limitations (OAT, wind) for the use of hot water as the first-step fluid in a two-step deicing operation.

To satisfy this objective, tests on flat plates were conducted at the National Research Council Canada (NRC), Climatic Engineering Facility (CEF) in Ottawa. Findings from previous studies were considered in the design of the experiment. Test parameters included temperature, wind, active precipitation, and testing on plates fabricated from typical aircraft composite materials as well as from aluminum. Because heat transfer to the test surface was a key element of the study, the thermal impact that accompanies removal of a surface contamination was also considered. The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least 3 minutes was the key indicator of acceptable temperature and wind limits.

## 2. PREVIOUS RELATED STUDIES.

### 2.1 HOT WATER DEICING TRIALS FOR THE 1994-95 WINTER.

This study, TP 12653E, was commissioned to generate the scientific data necessary to support a rational determination of the lower OAT limit for application of hot water as a first-step deicing fluid [2]. At the time the report was commissioned, the lower OAT limit had only recently been modified from -7° to -3°C. This reduction was based solely on operator comments. This study examined whether the OAT limitation for the application of hot water could safely be lowered beyond -3°C. The study, conducted primarily on aircraft, indicated that hot water deicing is feasible at temperatures below -3°C, depending on wind speed and operator disciplines. The earliest occurrence of freezing occurred on flight control surfaces at the rear of the wing, not on the main wing surface.

Tests carried out in a controlled environment laboratory confirmed that high winds exert a major influence on shortening the time interval in which the earliest freezing occurs. During field trials, deicing personnel experienced in hot water deicing commented that a cautious approach is necessary even at moderate temperatures during conditions of high wind. The study recommended that any further tests should consider the effect of winds. Additionally, an examination of the effect of the more modern aviation composite materials, which are frequently used in the fabrication of aircraft lift surfaces, was also recommended.

Figure 2-1 plots results from three field tests performed on a McDonnell Douglas DC-9 aircraft. The tests were conducted in dry conditions. These tests included the removal of contamination from the wing that had formed in previous trials. The data points indicate the time to the onset of freezing, following spray application of hot water, for various OATs. The wind speed at the time of testing is also shown. The data points shown are the most severe (shortest times to freezing) of several locations measured on the wing, and were generally located on flight control surfaces. The box in the lower right hand corner indicates the extent of currently approved limits.

Figure 2-2 adds results from laboratory tests to the previous chart. In these trials, 0.5 L of heated water was poured on a clean plate. The laboratory data points illustrate the influence of wind on the time interval that elapsed before the onset of freezing. The chart also shows a data point generated in an independent field study (Transportation Development Centre report, TP 12735E [4], *Aircraft Ground Operations in Canadian Winter Weather*).

Figure 2-3 proposes a model to assist determination of operational limits for the combination of OAT and wind. A family of hypothetical curves is proposed, that could potentially define the relationship between time to the onset of freezing and OAT for various incremental wind speeds. These curves were hypothesized from results of several tests in the lab and aircraft field tests. The term hypothetical is used to describe this figure to ensure that the reader does not assume that these curves are fully supported by data and could be put into practice.

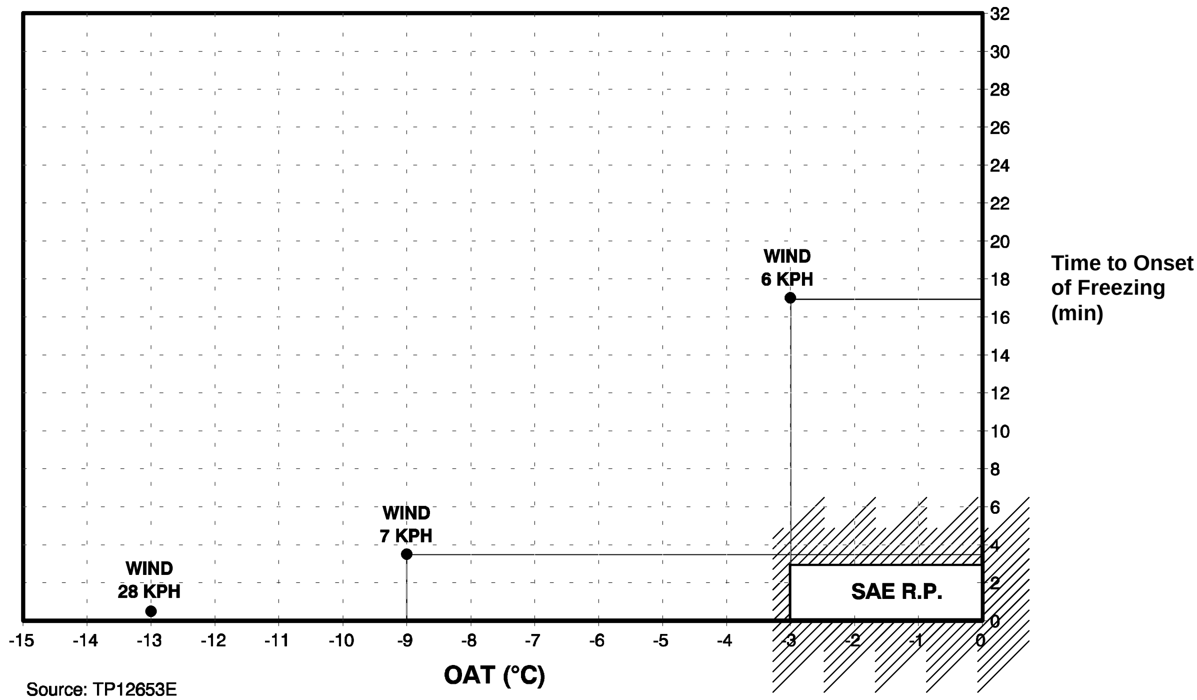



FIGURE 2-1. HOT WATER DEICING TRIALS – AIRCRAFT (NO PRECIPITATION, MARCH - APRIL 1995)

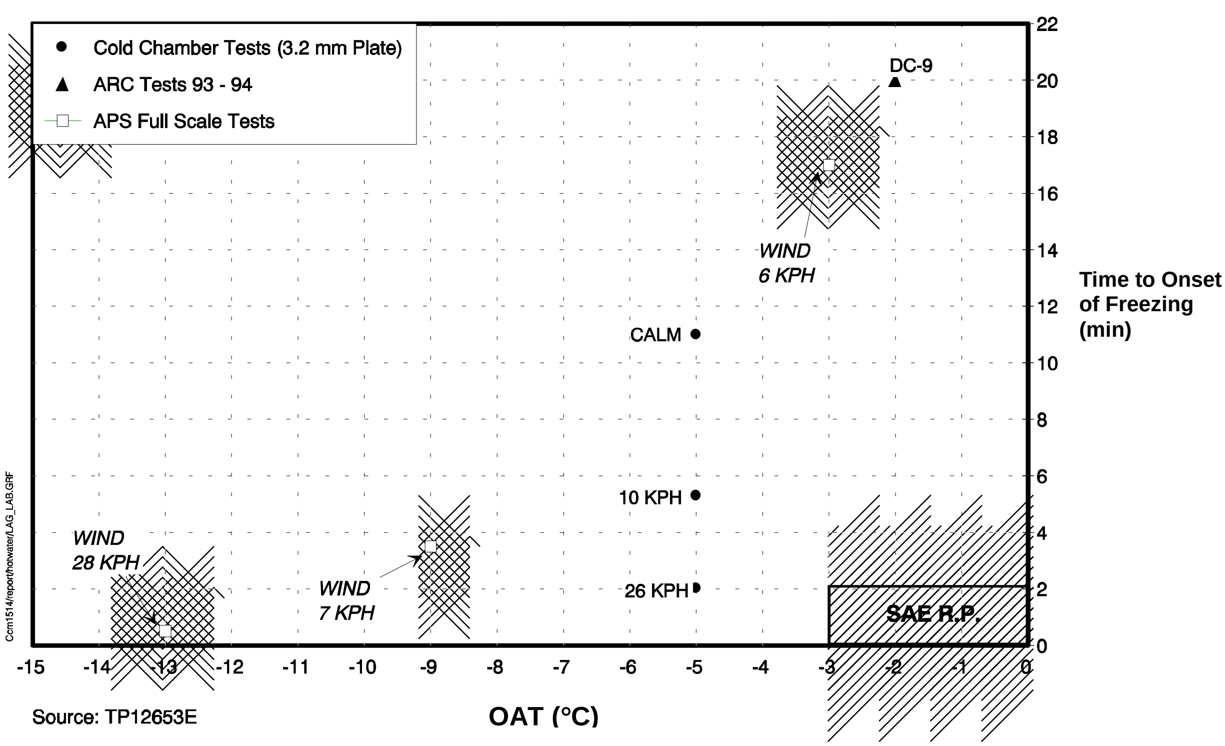



FIGURE 2-2. HOT WATER DEICING TRIALS – AIRCRAFT AND LABORATORY (NO PRECIPITATION, MARCH - APRIL 1995)

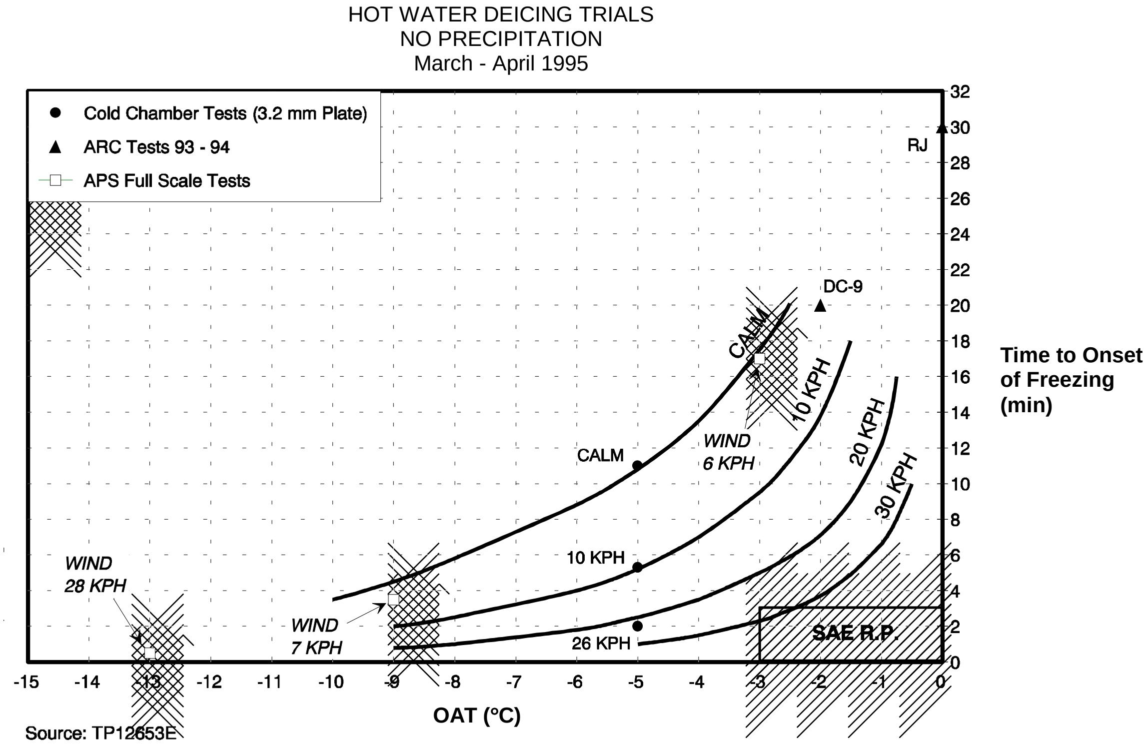



FIGURE 2-3. HYPOTHETICAL CURVES – RELATING TIME TO ONSET OF FREEZING WITH OAT FOR INCREMENTAL WIND SPEED

## 2.2 1997-98 STUDY ON FLUID FREEZE POINT BUFFER REQUIREMENTS FOR FIRST-STEP FLUIDS.

This study, TP 13315E, examined the use of very dilute (-3°C buffer) Type I fluids (as well as water) as first-step deicing fluids, and determined the resultant interval until freezing began [3]. These trials differed from the previous hot water trials in that these tests were conducted in precipitation conditions. Again, 0.5 L of heated fluid was poured onto a clean test plate. Trials were conducted at a range of temperatures, under freezing rain and freezing drizzle precipitation. Later, during the progress of the study, a test procedure for combining wind and precipitation conditions was devised, and a small number of trials at one temperature but with several wind speeds were conducted. Figure 2-4 is a chart of test results for hot water. The chart plots the time to the onset of freezing versus OAT. Data for different wind speeds were generated at only one OAT.

This study (1997-98) also included an examination of the rate of dilution of the applied Type I fluids under the test levels of precipitation. Figure 2-5 is a plot of surface temperature and fluid freeze point over time. The surface cools after the application of fluid and is diluted under ongoing precipitation. In the test reported in this figure, the Type I fluid was mixed to the currently approved limit for first-step fluids wherein the fluid freeze point may be 3 degrees above the OAT. Figure 2-6 plots the same data for a neat Type I fluid, and demonstrates how quickly a fluid, which is initially in its standard concentration, approximately 50/50, is diluted to the point where its freeze point (FP) is at the OAT.

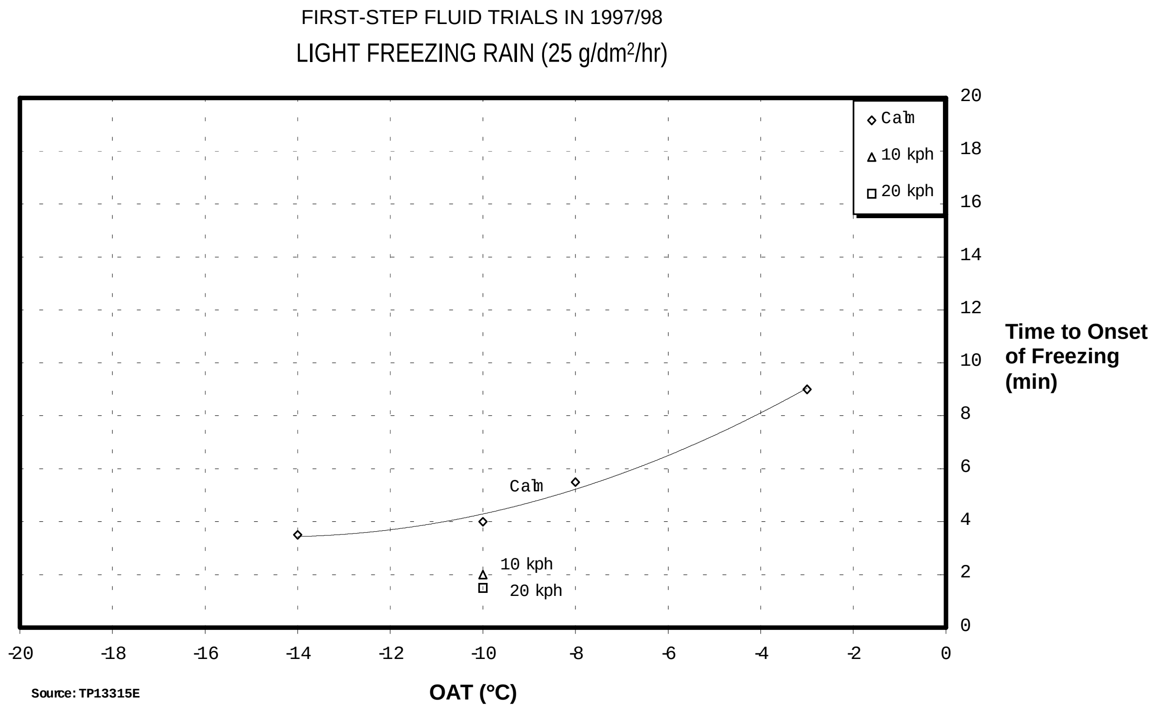



FIGURE 2-4. TIME TO ONSET OF FREEZING – HOT WATER

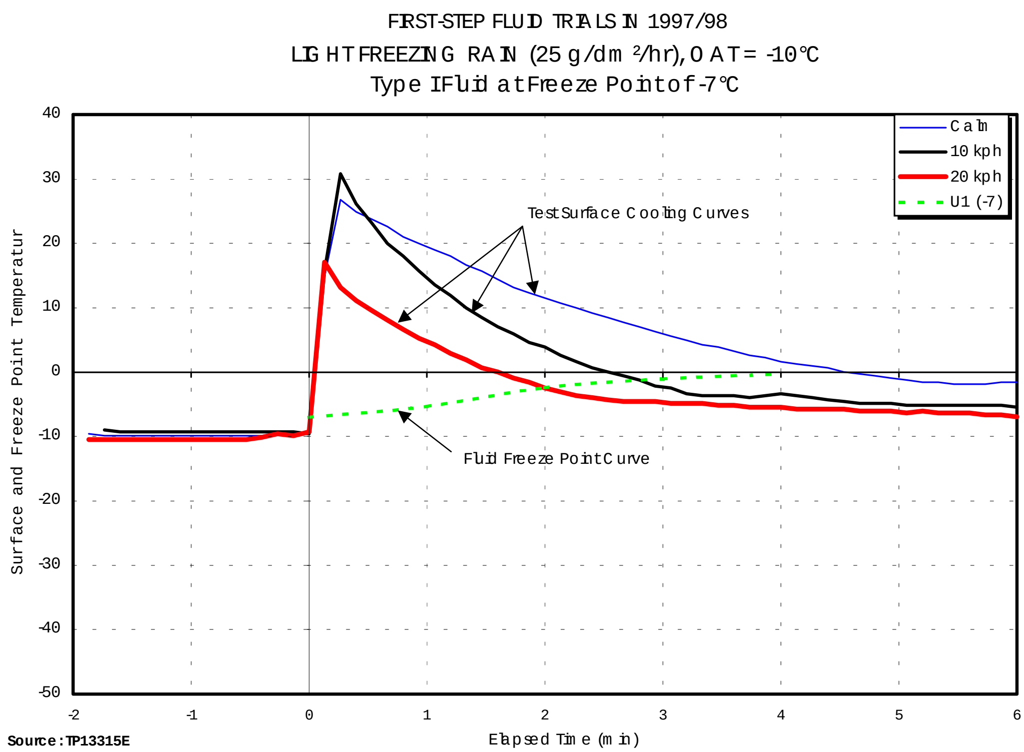



FIGURE 2-5. TEMPERATURE PROFILES OF TEST SURFACE AND FLUID FREEZE POINT – LIGHT FREEZING RAIN

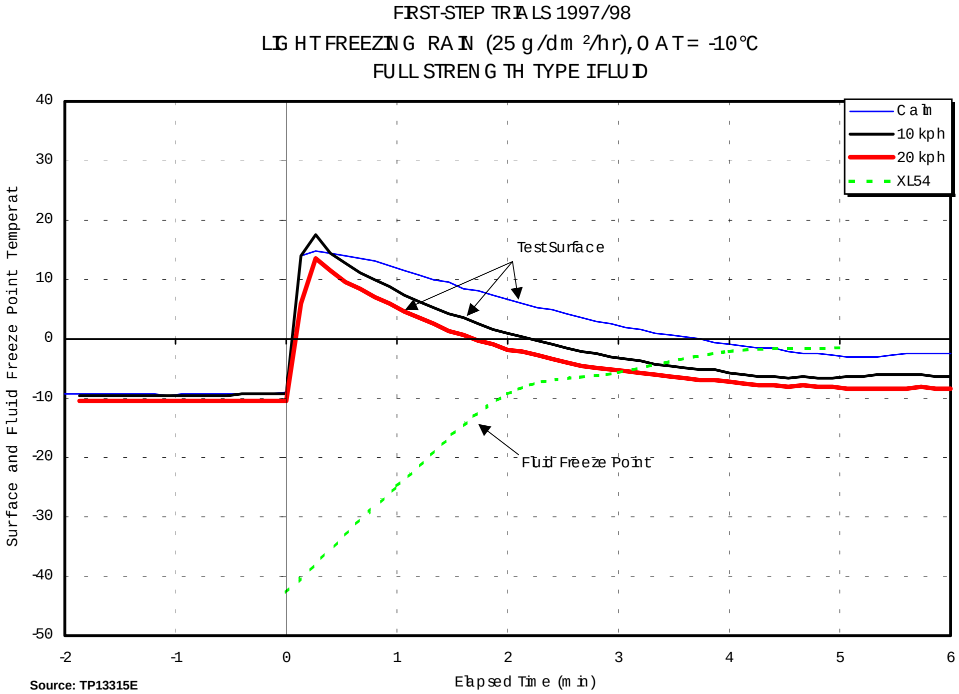



FIGURE 2-6. SURFACE TEMPERATURE VERSUS FLUID FREEZE POINT FOR VARIOUS WIND SPEEDS – LIGHT FREEZING RAIN

In figure 2-5, it was shown that the fluid diluted to zero concentration in about 4 minutes. Test results demonstrated that heat transfer to the test surface from the first-step fluid was the major contributor to the span of the time interval until freezing initiated:

- In calm conditions, the surface cooled to 0°C in 4.5 minutes. In this case, the fluid freeze point curve indicates that at the point of freezing initiation, the fluid was already diluted to an insignificant glycol concentration. Therefore, freezing point depression (FPD) provided no contribution to the elapsed time until onset of freezing.

- At a wind speed of 10 kph, the fluid freeze point curve intersected the surface temperature curve slightly after the temperature curve crossed 0°C. At this wind speed, the Type I fluid could be said to perform equivalently to hot water.

- At a wind speed of 20 kph, the fluid freeze point curve intersected the surface temperature curve about 0.5 minutes after the temperature curve crossed 0°C. At this wind speed, the surface heat provided protection for 1.5 minutes and the FPD action added a further 0.5 minutes of protection.

Figure 2-6 provides similar information for an application of full-strength Type I fluid.

Note: The *elapsed times until freezing* inferred from the intersection of the curves in figure 2-5 are slightly longer than *time to onset of freezing* reported in figure 2-4. This is a result of the method used to measure surface temperature wherein surface temperature (reported in figure 2-5) was obtained by contact measurement instrumentation at only one point, near the geometrical center of the test plate. Time to onset of freezing (reported in figure 2-4) was based on visual observation of the first sign of freezing. This usually occurred near the edge of the test plate where the surface temperature is generally cooler than at the point of surface temperature measurement.

## 2.3 1997-98 DEICING ONLY STUDY.

This study, TP 13315E, examined the use of very dilute fluids to remove any contamination following termination of precipitation, when ongoing protection as provided by anti-icing fluid is not required [3]. The study included measurement of the rate of cooling of the test surface for different wind and OAT combinations in nonprecipitation conditions. This information is useful for providing an indication of the time interval following application of the deicing fluid until the surface temperature reaches 0°C, for various OAT/wind combinations.

Figure 2-7 is a chart of results obtained from trials using hot water. Here, the time interval (at various wind speeds) until the plate temperature drops to 0°C, is plotted versus OAT. Again in these trials, 0.5 L of water at 60°C was applied to each clean plate, marking the beginning of each test. For these tests the hot water was applied using a specially fabricated fluid spreader. This device, into which was poured 0.5 L of hot water, was positioned at the top of the plate and the hot water flowed downward across the width of the plate. The results from the 1997-1998 studies on deicing only, and the results from fluid freeze point buffer requirements for first-step fluids, were discussed in detail at the annual 1998 SAE G-12 Committee Aircraft Ground Deicing meeting, and also at a special meeting convened for that purpose and held in August 1998 at the FAA William J. Hughes Technical Center, Atlantic City International Airport.

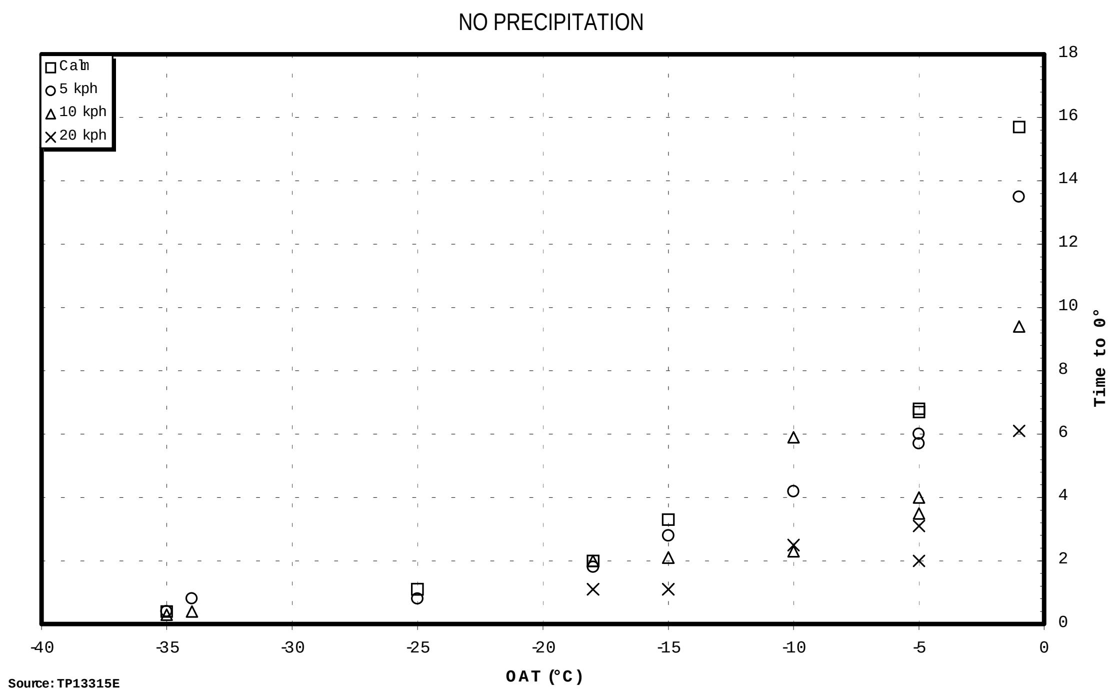



FIGURE 2-7. INFLUENCE OF OAT AND WIND ON PLATE COOLING RATE
*DEICING ONLY* TRIALS – HOT WATER

As a result of discussions at those meetings, further investigation of the *deicing only* application was conducted in order to examine the effects of varying several test parameters. One variable examined was the removal of snow contamination from the test surface, to ascertain whether the act of removing snow diminished the final transfer of heat to the surface. This factor was examined both in the laboratory and in the field on an aircraft wing. The test methodology was based on actual operations, and allowed the spray operator to continue spraying until the surface was clean.

In general, it was concluded that the greater the amount of contamination, the greater was the quantity of fluid that was applied by the operator, and the greater quantity of fluid compensated for any loss of heat in the snow removal process. Limited testing indicated that the presence of snow did not significantly affect fluid performance.

## 2.4 IMPLICATIONS FOR CURRENT TESTS.

All previous studies confirmed that in addition to OAT, wind effects are very significant in determining the time interval following application of spray until onset of freezing. This was evident from tests conducted in both dry (nonprecipitation) and in active precipitation conditions. Tests under freezing precipitation (first-step fluid study) appeared to produce values for elapsed time until onset of freezing that were somewhat shorter than in dry conditions. These observations indicate that the test design should include controlled combinations of wind and precipitation.

Previous studies indicate that when the OAT is lower than -12ºC, the time interval from spray application until onset of freezing is too short for operational practice. It was decided that a test design based on OAT values of -3°, -6°, -9°, and -12°C would offer sufficient data for chart construction.

During industry discussions on the results of the *deicing only* study, several points of interest were raised that could be realistically addressed in the design of a test program for hot water deicing. Those points of interest are:

- *Effect of actual removal of contaminant from the surface*. Based on current year trials to supplement deicing only data, the process of removal of contamination by spraying appears to be self-compensating in the sense that the additional quantity of fluid required to remove the contaminant compensates for any heat loss to the contaminant.

- *Test surfaces composed of composite materials*. Trials should be conducted on test surfaces composed of composite materials, representative of aircraft construction, for the deicing only study.

- *Tests on fluids mixed to currently authorized freeze point limits to serve as a reference when examining test results*. Type I fluid mixed to a fluid freeze point 3ºC above OAT (first-step fluid limitation) should be tested in addition to hot water.

The industry transition from heated Type I fluid to unheated non-Newtonian fluid as the second-step anti-icing fluid has brought about a particular concern. When hot water deicing was practiced in the past, before the advent of the modern SAE Type IV fluids, the second-step anti-icing spray generally consisted of a heated Type I fluid. The heat from the second-step fluid served to correct any early freezing of the applied water not noted by the operator.

The loss of this inherent corrective function with the use of unheated anti-icing fluids is not addressed in this test program, other than designing the test around rigorous parameters. Any procedures and guidelines that emerge from this study must have as a goal the provision of a clean surface that remains unfrozen for a reasonable period after the first-step fluid application.

It should be added that an investigation into the use of warmed anti-icing fluids led to significantly reduced holdover times due to reduced fluid viscosity and associated thinner stabilized fluid film thickness [5].

## 3. METHODOLOGY.

This section describes the conditions and methodologies used in these tests, as well as the test equipment and personnel requirements.

### 3.1 TEST SITE.

These tests were conducted at the NRC CEF located near Ottawa International Airport.

Experimental trials for the winter 1997-98 study on aircraft deicing fluid freeze point buffer requirements for first-step fluids [3] were also conducted in this facility. During the 1997-98 trials, an approach to provide a controlled combination of wind and precipitation for test purposes was developed. In that approach, the entire facility, encompassing both the large and the small chambers, was utilized.

The previous approach was enhanced for the 1998-99 trials by relocating the precipitation spray head to a location in the large chamber. This allowed placement of fans for wind production in the same chamber, thereby avoiding the excessive turbulence experienced previously from the structure dividing the two chambers. The freezing rain sprayer head is shown in figure 3-1.

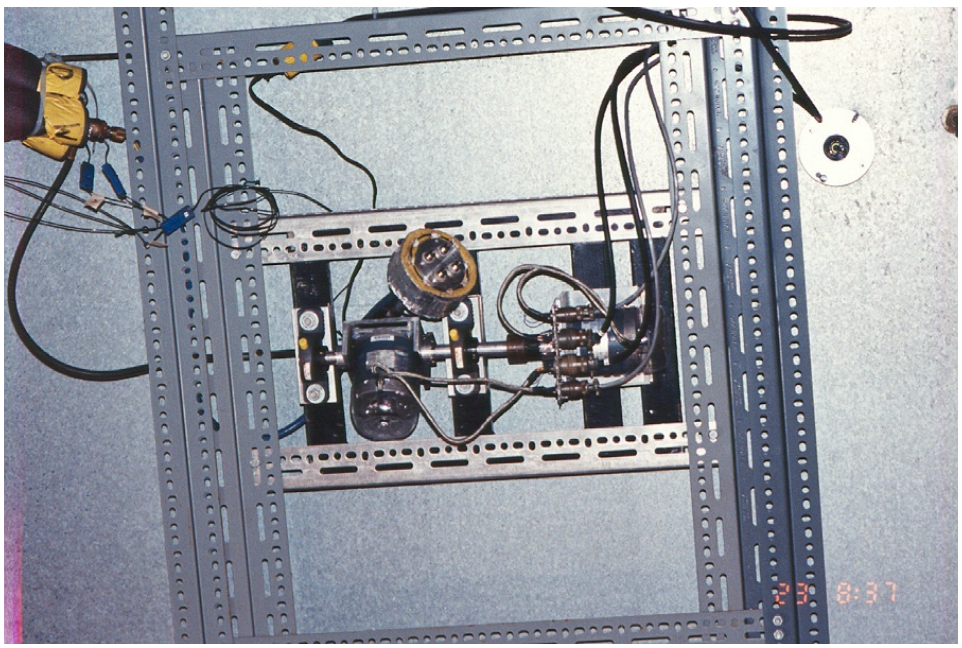


FIGURE 3-1. FREEZING RAIN SPRAYER

### 3.2 DESCRIPTION OF TEST PROCEDURES.

Tests were scheduled over a 3-day period at the NRC CEF facility.

The test variables included air temperature and wind speed. A precipitation condition of freezing rain at a rate of 25 g/dm$^2$/hr was established. Precipitation rates were measured over the entire stand at the beginning and at the end of each test session, as well as on a continuing basis every

20 minutes. This methodology is based on the standard procedure established in the experimental methodology for determining fluid holdover times (HOT). Figure 3-2 shows collection pans being weighed as part of this procedure. The distribution of raindrops over the plate surface is shown in figure 3-3. In this figure, the bare plate, which had been cooled to ambient temperature (-12°C), was subjected to freezing rain precipitation at the test rate (25 g/dm$^2$/hr) for a 1-minute interval. The drops froze immediately upon striking the bare plate surface. The resulting pattern of frozen rain droplets reflects an even distribution over the plate surface.


FIGURE 3-2. WEIGHING PLATE PANS IN MEASURING PRECIPITATION PLATE

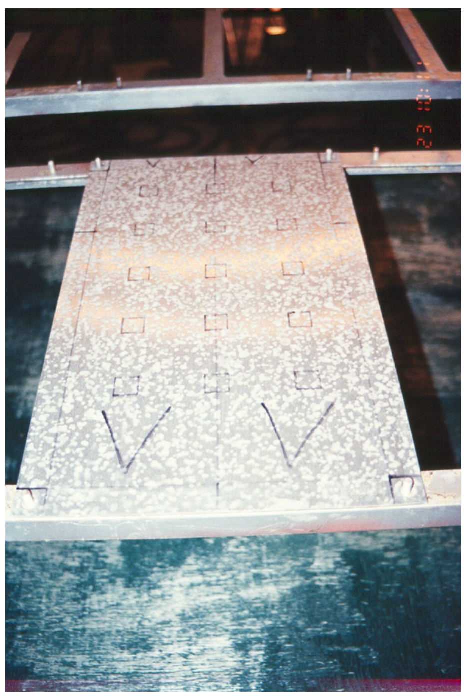


FIGURE 3-3. DISTRIBUTION OF RAIN DROPLETS OVER PLATE SURFACE

Aluminum plate test surfaces (300 × 500 × 3.2 mm) were prepared in advance. Plates were buffed, removing all traces of markings. Each was marked with an identification label. No grid marks were allowed to remain on plate surfaces in order to avoid damming of fluid runoff. A single thermistor probe was installed on each test plate at the 22.5 cm (9″) line. Figure 3-4 shows probes being installed on the plates on the upper row. Plates were mounted on a standard flat plate test stand at slope of 10°, as shown in the general test setup figure 3-5.

FIGURE 3-4. THERMISTOR PROBES ON ALUMINUM PLATES

FIGURE 3-5. GENERAL TEST SETUP

Testing with Type I deicing fluids was included to provide a reference to current operational practices. Type I fluid was tested both at full strength (approximately 50/50) and diluted to currently approved levels (freeze point = 3°C above OAT).

Fluid mixes were prepared in advance. For tests involving Type I fluid, a duplicate test plate was conducted to enable sampling for measurement of fluid dilution rates, without disturbing the test plate used to record observations.

Industry discussions of results from a similar study involving heat transfer from a heated fluid to the test surface (the 1997-1998 study on fluid freeze point buffer requirements for deicing only conditions [3] raised a concern regarding testing on bare surfaces. The concern was that some of the fluid's heat might be dissipated by the actual removal of solid contamination, thereby decreasing the amount of heat transferred to the surface. To address that concern, these trials were designed to incorporate the removal of contamination from the test surface as part of the test procedure.

A controlled level of contamination was allowed to collect on the plates prior to each test by exposing the plate to precipitation for a predetermined time interval. This exposure time interval was evaluated for each temperature condition, with the objective of standardizing the degree of plate contamination for all conditions as much as possible. This resulted in a standard exposure time of 1 minute for all temperatures tested. The exposure time was varied to study the effect of increased levels of contamination.

The resulting layer of ice contamination was then removed by spraying as much fluid as was required to provide a clean plate. Figures 3-6 and 3-7 show fluid being applied by spraying. Figure 3-6 clearly shows the ice contaminant being removed, resulting in a clean plate surface as the spray operator works his way down the plate from top to bottom. The distance from nozzle to surface was generally as shown in the figures, and typically in the range of 10 to 15 cm.

FIGURE 3-6. CLEANING ICE FROM PLATE WITH SPRAYED FLUID

FIGURE 3-7. SPRAY APPLICATION

The time of spray application was recorded, as was the time interval until the initiation of freezing. The elapsed time to the onset of freezing was the key element being measured in these trials. This parameter was a visual observation.

Fluid sprayers were constructed specifically to simulate spraying in field operations. These sprayers were precalibrated to enable calculation of the fluid quantity sprayed. The fluid quantities were based on records of spray duration.

In some of the trials that demonstrated times until freezing shorter than 3 minutes, a second test was conducted with additional fluid sprayed, to determine how much additional fluid would be necessary to achieve a 3-minute time to freezing.

Fluids were heated to 60°C at the time of application. Temperature and Brix values of fluids were measured prior to fluid application.

The time interval until the initial appearance of freezing was the most critical data recorded.

Plate temperatures were monitored throughout the tests by means of thermistor probes, which were installed on plate surfaces. Data loggers were used to automatically record these temperatures. Test surface temperatures were allowed to return to the ambient laboratory temperature prior to proceeding with the next test.

Periodically, fluid strength was measured on duplicate plates during each test. Measurements were taken at a frequency sufficient to construct a fluid freeze point temperature profile over time. The procedure for lifting samples for fluid strength measurement attempted to collect a representative mix of fluid by running the fluid sampler the full length of the plate, from bottom to top, but avoiding picking up fluid from the drip line. Fluid strength was measured using Brix-scale refractometers (figure 3-8).

FIGURE 3-8. BRIX REFRACTOMETER

A video and photographic record of the test setup was maintained.

Table 3-1 presents an overview of test parameters for these trials. The plan called for four OAT conditions with four values of wind speeds at each. Both water and SAE Type I fluids (mixed to a FP 3ºC above OAT) were tested. In addition to the standard aluminum test surfaces, surfaces fabricated from composite materials typically used in aircraft manufacture were also tested.

Table 3-2 provides the detailed test plan and defines the specific parameter(s) varied in each test.

During the course of the trials, certain anomalies were observed in the test results. These were explored further through a complementary set of tests, listed in table 3-3. This series of tests examined the impact of the duration of spray application, and also examined the impact of the method of fluid application (spraying versus pouring).

TABLE 3-1. TEST PLAN FOR HOT WATER TRIALS

| OAT (°C) | FLUID | WIND (kph) | TEST SURFACE |
|---|---|---|---|
| -3 | Water | Calm | Standard Aluminum test plate for all conditions.<br>Composite surface for selected conditions. |
| | | 10 | |
| | | 20 | |
| | | 30 | |
| -6 | Water<br>Type I ADF, Freeze Point -3°C | Calm | |
| | | 10 | |
| | | 20 | |
| | | 30 | |
| -9 | Water<br>Type I ADF, Freeze Point -6°C | Calm | |
| | | 10 | |
| | | 20 | |
| | | 30 | |
| -12 | Water<br>Type I ADF, Freeze Point -9°C | Calm | |
| | | 10 | |
| | | 20 | |
| | | 30 | |

**NOTES:**

Precipitation rate - light freezing rain 25 g/dm²/hr

Fluid heated to 60°C

Fluid applied by spraying

TABLE 3-2. HOT WATER TRIALS – TEST SCHEDULING AND CONTROL SHEET

## TEST SCHEDULING AND CONTROL SHEET

| | | |
|---|---|---|
| PRECIPITATION: | Light Freezing Rain at 25 g/dm²/hr | |
| FLUID TEMPERATURE: | 60°C at the Nozzle | |
| <u>TEST SURFACE TYPES:</u> | Aluminum | Al |
| | Aluminum Honey Comb | C1 |
| | Carbon Fibre on Honey Comb | C3 |
| | Glass Fibre on Honey Comb | C4 |
| | Kevlar on Honey Comb | C5 |

**<u>Note</u>**: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3-minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

| Proposed Test Period | Time Fluid Needed | Test Team | Run # | Test Objective | OAT (°C) | Fluid Type | Wind (kph) | Surface Type | Plate Exposure Time |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | Initial Ice | -3 | Water | Calm | Al | |
| | | | 2 | Initial Ice | -3 | Water | 10 | Al | |
| | | | 3 | Initial Ice | -3 | Water | 10 | C1 | |
| | | | 4 | Initial Ice | -3 | Water | 10 | C3 | |
| | | | 5 | Initial Ice | -3 | Water | 10 | C4 | |
| | | | 6 | Initial Ice | -3 | Water | 10 | C5 | |
| | | | 7 | Initial Ice | -3 | Water | 20 | Al | |
| | | | 8 | Initial Ice | -3 | Water | 30 | Al | |
| | | | 9 | Initial Ice | -6 | Water | Calm | Al | |
| | | | 10 | Initial Ice | -6 | T1E -3 | Calm | Al | |
| | | | 11 | Brix | -6 | T1E -3 | Calm | Al | |
| | | | 12 | Initial Ice | -6 | Water | 10 | Al | |
| | | | 13 | Initial Ice | -6 | Water | 10 | C1 | |
| | | | 14 | Initial Ice | -6 | Water | 10 | C3 | |
| | | | 15 | Initial Ice | -6 | Water | 10 | C4 | |
| | | | 16 | Initial Ice | -6 | Water | 10 | C5 | |
| | | | 17 | Initial Ice | -6 | T1E -3 | 10 | Al | |
| | | | 18 | Initial Ice | -6 | T1E -3 | 10 | C1 | |
| | | | 19 | Initial Ice | -6 | T1E -3 | 10 | C3 | |
| | | | 20 | Initial Ice | -6 | T1E -3 | 10 | C4 | |
| | | | 21 | Initial Ice | -6 | T1E -3 | 10 | C5 | |
| | | | 22 | Brix | -6 | T1E -3 | 10 | Al | |
| | | | 23 | Initial Ice | -6 | Water | 20 | Al | |
| | | | 24 | Initial Ice | -6 | T1E -3 | 20 | Al | |
| | | | 25 | Brix | -6 | T1E -3 | 20 | Al | |
| | | | 26 | Initial Ice | -6 | Water | 30 | Al | |
| | | | 27 | Initial Ice | -6 | T1E -3 | 30 | Al | |
| | | | 28 | Brix | -6 | T1E -3 | 30 | Al | |
| | | | 29 | Initial Ice | -9 | Water | Calm | Al | |
| | | | 30 | Initial Ice | -9 | T1E -6 | Calm | Al | |
| | | | 31 | Brix | -9 | T1E -6 | Calm | Al | |
| | | | 32 | Initial Ice | -9 | Water | 10 | Al | |
| | | | 33 | Initial Ice | -9 | Water | 10 | C1 | |
| | | | 34 | Initial Ice | -9 | Water | 10 | C3 | |

# TABLE 3-2. HOT WATER TRIALS – TEST SCHEDULING AND CONTROL SHEET (Continued)

## TEST SCHEDULING AND CONTROL SHEET

PRECIPITATION: Light Freezing Rain at 25 g/dm²/hr

FLUID TEMPERATURE: 60°C at the Nozzle

| TEST SURFACE TYPES: | | |
|---|---|---|
| | Aluminum | Al |
| | Aluminum Honey Comb | C1 |
| | Carbon Fibre on Honey Comb | C3 |
| | Glass Fibre on Honey Comb | C4 |
| | Kevlar on Honey Comb | C5 |

**Note**: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3-minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

| Proposed Test Period | Time Fluid Needed | Test Team | Run # | Test Objective | OAT (°C) | Fluid Type | Wind (kph) | Surface Type | Plate Exposure Time |
|---|---|---|---|---|---|---|---|---|---|
| | | | 35 | Initial Ice | -9 | Water | 10 | C4 | |
| | | | 36 | Initial Ice | -9 | Water | 10 | C5 | |
| | | | 37 | Initial Ice | -9 | T1E -6 | 10 | Al | |
| | | | 38 | Initial Ice | -9 | T1E -6 | 10 | C1 | |
| | | | 39 | Initial Ice | -9 | T1E -6 | 10 | C3 | |
| | | | 41 | Initial Ice | -9 | T1E -6 | 10 | C5 | |
| | | | 42 | Brix | -9 | T1E -6 | 10 | Al | |
| | | | 43 | Initial Ice | -9 | Water | 20 | Al | |
| | | | 44 | Initial Ice | -9 | T1E -6 | 20 | Al | |
| | | | 45 | Brix | -9 | T1E -6 | 20 | Al | |
| | | | 46 | Initial Ice | -9 | Water | 30 | Al | |
| | | | 47 | Initial Ice | -9 | T1E -6 | 30 | Al | |
| | | | 48 | Brix | -9 | T1E -6 | 30 | Al | |
| | | | 49 | Initial Ice | -12 | Water | Calm | Al | |
| | | | 50 | Initial Ice | -12 | T1E -9 | Calm | Al | |
| | | | 51 | Brix | -12 | T1E -9 | Calm | Al | |
| | | | 52 | Initial Ice | -12 | Water | 10 | Al | |
| | | | 53 | Initial Ice | -12 | Water | 10 | C1 | |
| | | | 54 | Initial Ice | -12 | Water | 10 | C3 | |
| | | | 55 | Initial Ice | -12 | Water | 10 | C4 | |
| | | | 56 | Initial Ice | -12 | Water | 10 | C5 | |
| | | | 57 | Initial Ice | -12 | T1E -9 | 10 | Al | |
| | | | 58 | Initial Ice | -12 | T1E -9 | 10 | C1 | |
| | | | 59 | Initial Ice | -12 | T1E -9 | 10 | C3 | |
| | | | 60 | Initial Ice | -12 | T1E -9 | 10 | C4 | |
| | | | 61 | Initial Ice | -12 | T1E -9 | 10 | C5 | |
| | | | 62 | Brix | -12 | T1E -9 | 10 | Al | |
| | | | 63 | Initial Ice | -12 | Water | 20 | Al | |
| | | | 64 | Initial Ice | -12 | T1E -9 | 20 | Al | |
| | | | 65 | Brix | -12 | T1E -9 | 20 | Al | |
| | | | 66 | Initial Ice | -12 | Water | 30 | Al | |
| | | | 67 | Initial Ice | -12 | T1E -9 | 30 | Al | |
| | | | 68 | Brix | -12 | T1E -9 | 30 | Al | |

TABLE 3-3. REPEAT HOT WATER TESTS AT -9ºC – MARCH 25, 1999

| OAT (°C) | WIND | FLUID | RUN | TEST TYPE |
|---|---|---|---|---|
| -9 | CALM | Water | 901 | Pour 0.5 L clean plate |
| | | | 902 | Pour 0.5 L contaminated plate |
| | | | 903 | Regular spray |
| | | | 904 | Regular spray |
| | | | 905 | 20 sec spray |
| | | | 906 | 40 sec spray |
| | | Type I ADF Freeze Point -6°C | 907 | Regular spray |
| | | | 908 | Regular spray |
| | 10 kph | Water | 909 | Pour 0.5 L clean plate |
| | | | 910 | Pour 0.5 L contaminated plate |
| | | | 911 | Regular spray |
| | | | 912 | Regular spray |
| | | | 913 | 20 sec spray |
| | | | 914 | 40 sec spray |
| | | Type I ADF Freeze Point -6°C | 915 | Regular spray |
| | | | 916 | Regular spray |
| | 20 kph | Water | 917 | Regular spray |
| | | | 918 | Regular spray |
| | | Type I ADF Freeze Point -6°C | 919 | Regular spray |
| | | | 920 | Regular spray |

## 3.3 DATA FORMS.

Forms for gathering test data included:

- Data form for Hot Water Trials (figure 3-9);
- Brix Progression form for Hot Water Trials (figure 3-10);
- Precipitation Rate Measurement Form (figure 3-11); and
- Continuous Precipitation Rate Measurement Form (figure 3-12).

REMEMBER TO SYNCHRONIZE TIME 1998/99

**LOCATION:** CEF (Ottawa) **DATE:** March ,1999 **AMBIENT TEMPERATURE:** °C

| | RH | Wind Speed (kph) | | | |
|---|---|---|---|---|---|
| | (%) | Top Left | Top Right | Bottom Left | Bottom Right |
| Start | | | | | |
| End | | | | | |

| | | | |
|---|---|---|---|
| **Run #:** | ______ | ______ | ______ |
| **Surface Type:** | ______ | ______ | ______ |
| **Fluid Type:** | ______ | ______ | ______ |
| **Fluid Brix:** | ______ ° | ______ ° | ______ ° |
| **Fluid Temperature:** | ______ °C | ______ °C | ______ °C |
| **Plate Exposure Start Time:** | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) |
| **Spray Start Time:** | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) |
| **Spray Finish Time:** | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) | ______ (hh:mm:ss:) |

**Plate #**

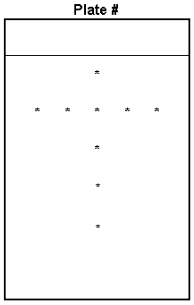


**Plate #**

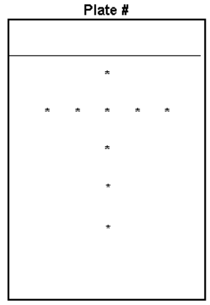
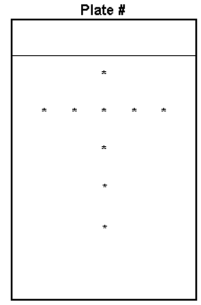


**Plate #**



| | | | |
|---|---|---|---|
| **Time to 1st Freezing:** | ______ | ______ | ______ |
| **Time to Failure (6" Line):** | ______ | ______ | ______ |
| **Time to complete Failure (15" Line):** | ______ | ______ | ______ |

**COMMENTS:** ______ **HAND WRITTEN BY :** ______

**LEADER:** ______

FIGURE 3-9. DATA FORM FOR HOT WATER TRIALS (LIGHT FREEZING RAIN)

**DATE:** March , 1999

**OAT:** ______ °C

| | RH (%) | Wind Speed (kph) | | | |
|---|---|---|---|---|---|
| | | Top Left | Top Right | Bottom Left | Bottom Right |
| Start | | | | | |
| End | | | | | |

---

**Plate Position:** ______ **Fluid Temperature:** ______ °C

**Run #:** ______ **Plate Exposure Start Time:** ______ (hh:mm:ss)

**Surface Type:** ______ **Spray Start Time** ______ (hh:mm:ss)

**Fluid Type:** ______ **Spray Finish time** ______ (hh:mm:ss)

**Fluid Brix:** ______ °

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | | | | | | | | | | |
| Brix | | | | | | | | | | |
| | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| Time (min) | | | | | | | | | | |
| Brix | | | | | | | | | | |

**Comments on Final Plate Condition:** ______

---

**Plate Position:** ______ **Fluid Temperature:** ______ °C

**Run #:** ______ **Plate Exposure Start Time:** ______ (hh:mm:ss)

**Surface Type:** ______ **Spray Start Time** ______ (hh:mm:ss)

**Fluid Type:** ______ **Spray Finish time** ______ (hh:mm:ss)

**Fluid Brix:** ______ °

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | | | | | | | | | | |
| Brix | | | | | | | | | | |
| | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| Time (min) | | | | | | | | | | |
| Brix | | | | | | | | | | |

**Comments on Final Plate Condition:** ______

---

**MEASUREMENTS BY:** ______ **HANDWRITTEN BY:** ______

FIGURE 3-10. BRIX PROGRESSION FORM FOR HOT WATER TRIALS

Date: ____________________

Start Time: ____________________ am/pm

Run #: ____________________

Precip Type: ____________________ (ZD, ZR-)

**Pan Location:**

| | | | | | |
|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** |
| **7** | **8** | **9** | **10** | **11** | **12** |

**Collection Pan:**

| Pan/ Cup # | Area of Pan (dm²) | Location | | Weight of Pan (g) | | Collection Time (min) | |
|---|---|---|---|---|---|---|---|
| | | | | Before | After | Start | End |
| 1 | | 1 | = | | | | |
| 2 | | 2 | = | | | | |
| 3 | | 3 | = | | | | |
| 4 | | 4 | = | | | | |
| 5 | | 5 | = | | | | |
| 6 | | 6 | = | | | | |
| 7 | | 7 | = | | | | |
| 8 | | 8 | = | | | | |
| 9 | | 9 | = | | | | |
| 10 | | 10 | = | | | | |
| 11 | | 11 | = | | | | |
| 12 | | 12 | = | | | | |

**Comments:** ____________________

**Handwritten by:** ____________________

**Measured by:** ____________________

FIGURE 3-11. PRECIPITATION RATE MEASUREMENT FORM

Date: __________

Start Time: __________

Run #: __________

Precip Type: __________ (ZD, ZR-)

**Pan Location:**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 |

**Collection Pan:**

| Pan/ Cup # | Area of Pan (dm²) | Location | Weight of Pan (g) | | Collection Time | | Rate |
|---|---|---|---|---|---|---|---|
| | | | Before | After | Start | End | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |

**Comments:**

**Handwritten by:** __________

**Measured by:** __________

FIGURE 3-12. CONTINUOUS PRECIPITATION RATE MEASUREMENT FORM

## 3.4 EQUIPMENT.

Some special equipment was needed to support these trials. Certain pieces were developed specifically for the project.

Large electric fans (figure 3-13) were provided by NRC. These fans, mounted on castor wheels, were located at a fixed position and speed was controlled by means of a rheostat on the power supply. This was a major improvement over previous trials, which required the fans to be repositioned between runs to provide different wind speeds. The accuracy in reproducing specific wind speeds for subsequent tests was enhanced by this feature.

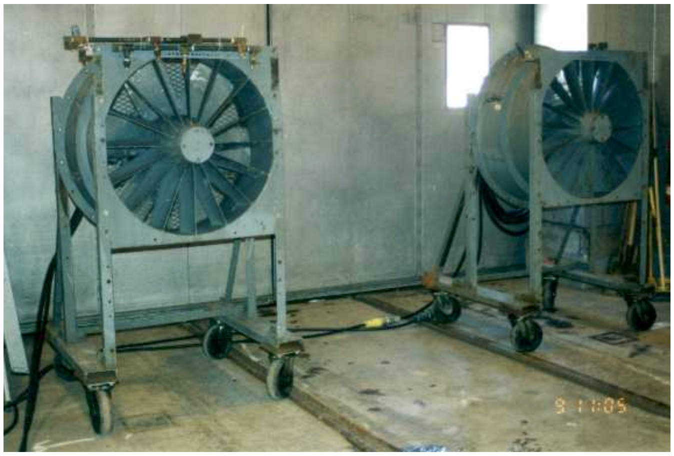


FIGURE 3-13. ELECTRIC FANS

Various concentrations of Type I fluid were needed. These fluid samples were heated using 5-litre aluminum pots (figure 3-14), hot plates, and a microwave oven (figure 3-15) for small fluid quantities.

FIGURE 3-14. TYPE I FLUID HEATING APPARATUS


FIGURE 3-15. MICROWAVE OVEN FOR HEATING SMALL QUANTITIES OF TYPE I FLUID

To satisfy the large demand for heated water (for the various hot water tests) a small water heater tank, mounted on a trolley for portability, was devised (figure 3-16). The tank was specially instrumented to provide an accurate reading of water temperature and fill level. The tank, pressurized with compressed air from the building supply, was incorporated into a self-contained water spray system. The water outlet from the tank was directed via a flexible hose to a spray nozzle, and thereby provided the heated water spray for the tests. The nozzle flow rate was calibrated to allow calculation of applied quantities of water based on the duration of spray. The flow rate was determined to be 25.5 ml/sec or 255 ml for 10-second spray duration. The external air supply provided a constant pressure in the tank thereby maintaining a constant application rate of the fluid mix or water regardless of change in liquid volume as it was expelled. A fluid temperature of 80°C in the tank supplied a temperature of 60°C at the nozzle (figure 3-17). The water heater tank was not suited for the application of Type I fluids due to the smaller total quantities of the various mixes required.

The Type I fluid was applied using a separate sprayer that had been developed for supplementary trials in the deicing only study, conducted earlier in the 1998-1999 season. The Type I fluid sprayer (figure 3-18) was based on a fire extinguisher tank, fitted with an air pressure supply fitting and a hose and nozzle assembly identical to the above-mentioned hot water tank. The tank was wrapped in insulation to maintain fluid temperatures. Prior to the tests, the two types of sprayers were tested and compared to ensure that they delivered common rates and patterns of spray.

Wind speeds were measured with a hand-held anemometer (figure 3-19).

A video camera, mounted on a tripod (figure 3-20) and trained on the test stand, was operated continuously to provide a continuous record of the of the test activities. A monitor and VCR recorder (figure 3-21) were linked to the video camera.


FIGURE 3-16. HOT WATER TANK

FIGURE 3-17. MEASURING WATER TEMPERATURE AT SPRAY NOZZLE

FIGURE 3-18. TYPE I FLUID SPRAYER


FIGURE 3-19. MEASURING WIND SPEED WITH ANEMOMETER

FIGURE 3-20. CONTINUOUS RECORDING WITH VIDEO CAMERA

FIGURE 3-21. VIDEO MONITOR AND VCR

In addition to standard aluminum test plates, plates fabricated from composite materials as used in new aircraft construction were tested. They included

- Aluminum on honeycomb backing
- Carbon Fibre on honeycomb backing
- Glass Fibre on honeycomb backing
- Kevlar on honeycomb backing

The aluminum honeycomb plate is shown in figure 3-22. The plates fabricated from carbon fibre, glass fibre, and Kevlar were painted with a grey polyurethane paint and consequently looked alike. Figure 3-23 shows a typical painted composite surface plate.

Each test plate was instrumented with a temperature thermistor probe and linked to data loggers.

## 3.5 FLUIDS.

Fluids used in these trials were heated water and heated SAE Type I fluid mixed to various concentrations. Type I fluid strength for testing was specified to provide a fluid FP 3 degrees above test OAT. In the report, a fluid code such as TIE -3 is used, meaning Type I fluid, ethylene glycol-base, freeze point of -3ºC. A full strength Type I fluid was used in some tests, shown as XL54 (std). UCAR Type I ADF fluid was used as the test fluid.

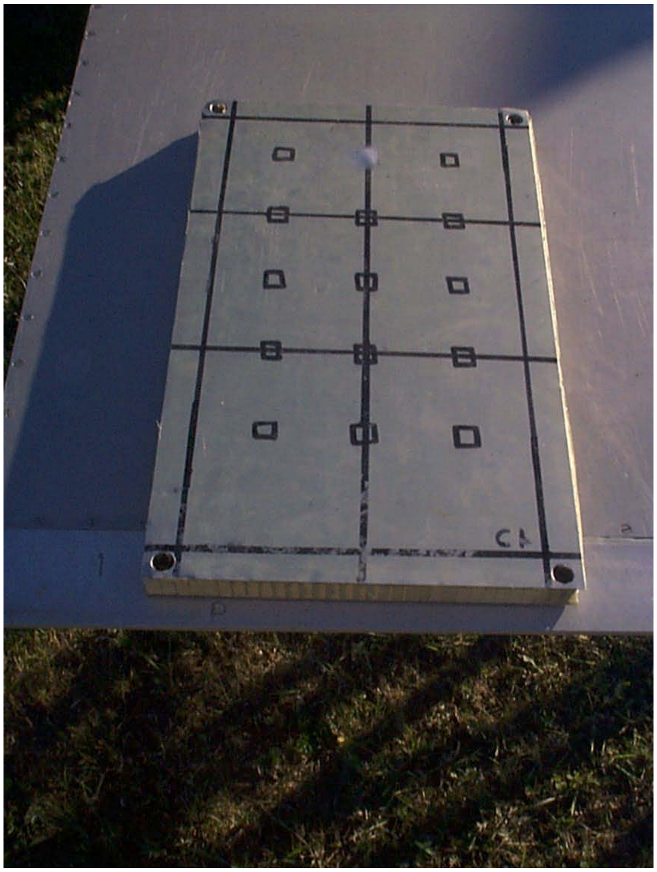


FIGURE 3-22.  TEST PLATE – ALUMINUM ON HONEYCOMB BACKING

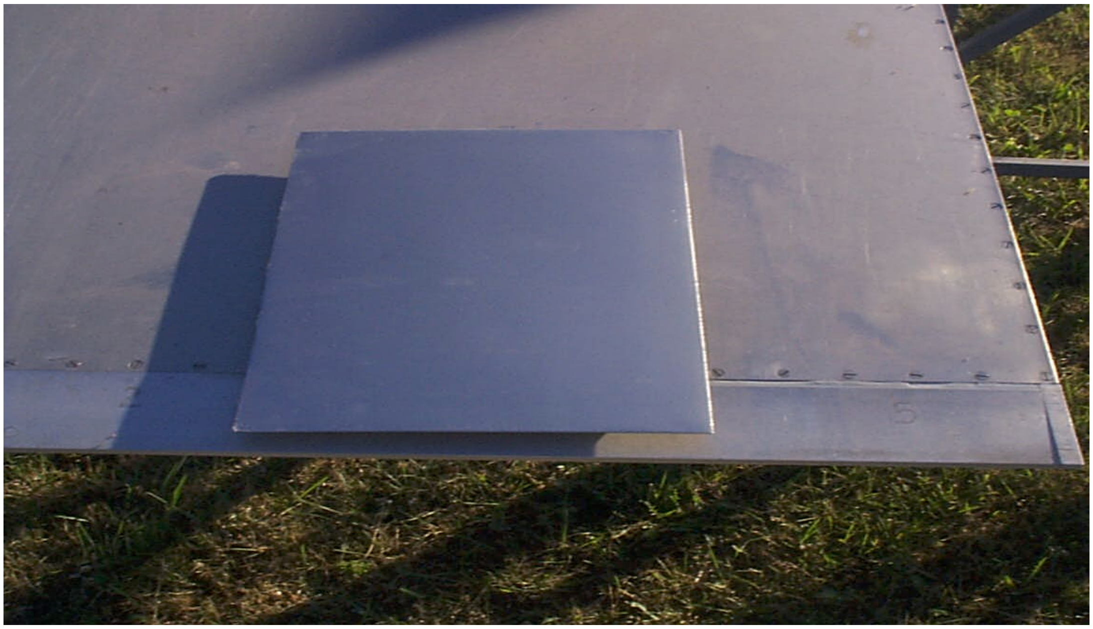


FIGURE 3-23.  TEST PLATE – COMPOSITE FIBRE ON HONEYCOMB BACKING

# 4. DESCRIPTION AND PROCESSING OF DATA.

## 4.1 OVERVIEW OF TESTS.

Tests were conducted from March 23 to 25, 1999. The initial test conditions were at the cold extreme (-12°C) of the range of test temperatures. Test condition temperatures were progressively increased over the 3-day period.

During the first series of tests (at the coldest test temperatures), it was noted that the time interval until first freezing occurred was less than the 3-minute target. To explore the causes of this shortfall, a number of tests were conducted with changes to various parameters. These included varying the amount of fluid sprayed, spraying with a different nozzle setting to produce a different spray pattern, and applying the fluid by pouring, using fluid spreaders as used in the Deicing Only and First-Step Fluid [3] study. Results of these variations are discussed in detail in section 5. Further variations in parameters were tested during the next two days of trials at progressively warmer temperatures are also discussed in this section.

A log of all trials conducted, including the special repeat trials conducted to explore test result anomalies, is presented in table 4-1. Some of the columns in this log require explanation.

- ID – is the sequential number of each test as it was conducted.
- Form – up to three tests could be recorded on a single data form. The data forms were numbered sequentially from the start of testing.
- Run – corresponds to the original run number in the detailed test plan (figure 3-10). Some of the runs were conducted more than once to provide a level of confidence in the results or to explore unexpected results. Also, some runs (where no number is assigned) were ad hoc trials conducted to explore the effect of changes in parameter values.
- Plate – is the number recorded on the plate, and on the thermistor probe. It serves to link the correct plate temperature data in the file to specific test runs.
- Plate exposure time – is the time that the plate was uncovered and exposed to precipitation to collect a layer of contamination.
- Spray Start Time & Spray Finish Time – the time difference is the total spray duration, and is used to calculate the amount of fluid applied.
- Time of 1$^{st}$ Freeze – is the time when freezing is first observed anywhere on the test surface. This interval is not equivalent to plate failure calls in holdover trials involving contamination over 1/3 of the plate surface, but corresponds to the *initial fluid failure* time.

# TABLE 4-1. HOT WATER DEICING AT NRC – WINTER 1999

| ID # | Form # | Date | Run # | Plate # | Surface Type | Fluid Type | Fluid Temp. (°C) | Ambient Temp (Design) (°C) | Ambient Temp (Actual) (°C) | Wind Speed kph | Plate Expos. Time | Spray Start Time | Spray Finish Time | Time of 1st Freeze | Time of Failure | Fluid Qty. (ml) | Exposure Interval (min) | Interval to 1st Freeze (min) | Interval to Complete Failure (min) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 23-Mar-99 | 49 | 1 | Aluminum | Water | 60 | -12 | -11.5 | 0 | 11:21:54 | 11:22:53 | 11:23:04 | 11:25:35 | 11:26:40 | 281 | 1.0 | 2.5 | 3.6 | |
| 2 | 1 | 23-Mar-99 | 49 | 3 | Aluminum | Water | 60 | -12 | -11.6 | 0 | 11:28:03 | 11:29:03 | 11:29:15 | 11:31:13 | 11:33:00 | 306 | 1.0 | 2.0 | 3.8 | |
| 3 | 1 | 23-Mar-99 | 49 | 2 | Aluminum | Water | 60 | -12 | -11.6 | 0 | 11:34:45 | 11:35:54 | 11:36:07 | 11:39:20 | 11:40:05 | 332 | 1.2 | 3.2 | 4.0 | |
| 4 | 2 | 23-Mar-99 | 49 | 1 | Aluminum | Water | 60 | -12 | -11.7 | 0 | 11:52:44 | 11:53:44 | 11:53:57 | 11:56:13 | 11:57:22 | 332 | 1.0 | 2.3 | 3.4 | |
| 5 | 2 | 23-Mar-99 | 49 | 3 | Aluminum | Water | 60 | -12 | -11.7 | 0 | 11:56:32 | 11:57:32 | 11:57:52 | 11:59:50 | 12:02:27 | 500 | 1.0 | 2.0 | 4.6 | 1/2 liter with sprayer |
| 6 | 2 | 23-Mar-99 | 49 | 2 | Aluminum | Water | 60 | -12 | -11.8 | 0 | 12:11:40 | 12:12:40 | 12:12:50 | 12:17:20 | 12:18:14 | 500 | 1.0 | 4.5 | 5.4 | 1/2 liter with spreader |
| 7 | 3 | 23-Mar-99 | 50 | 1 | Aluminum | T1E-9 | 60 | -12 | -11.9 | 0 | 12:18:56 | 12:19:58 | 12:20:10 | 12:22:20 | 12:23:41 | 306 | 1.0 | 2.2 | 3.5 | |
| 8 | 3 | 23-Mar-99 | 50 | 2 | Aluminum | T1E-9 | 60 | -12 | -11.9 | 0 | 12:24:27 | 12:25:27 | 12:25:38 | 12:28:40 | 12:29:40 | 281 | 1.0 | 3.0 | 4.0 | |
| 9 | 4 | 23-Mar-99 | 57 | 2 | Aluminum | T1E-9 | 60 | -12 | -12.1 | 10 | 13:53:19 | 13:54:19 | 13:54:30 | 13:55:40 | 13:56:45 | 281 | 1.0 | 1.2 | 2.3 | |
| 10 | 4 | 23-Mar-99 | 57 | 3 | Aluminum | T1E-9 | 60 | -12 | -12.1 | 10 | 13:57:00 | 13:58:00 | 13:58:11 | 13:59:00 | 14:00:40 | 281 | 1.0 | 0.8 | 2.5 | |
| 11 | 4 | 23-Mar-99 | 57 | 1 | Aluminum | T1E-9 | 60 | -12 | -12.1 | 10 | 14:00:30 | 14:01:30 | 14:01:50 | 14:03:17 | 14:04:50 | 510 | 1.0 | 1.5 | 3.0 | double fluid quantity sprayed |
| 12 | 5 | 23-Mar-99 | 58 | C1 | C1 | T1E-9 | 60 | -12 | -12.1 | 10 | 14:05:48 | 14:06:46 | 14:07:02 | 14:08:00 | 14:08:50 | 408 | 1.0 | 1.0 | 1.8 | |
| 13 | 6 | 23-Mar-99 | 58 | C1 | C1 | T1E-9 | 60 | -12 | -12.0 | 10 | 15:00:10 | 15:01:10 | 15:01:22 | 15:02:30 | 15:03:10 | 306 | 1.0 | 1.1 | 1.8 | |
| 14 | 6 | 23-Mar-99 | 59 | C3 | C3 | T1E-9 | 60 | -12 | -12.0 | 10 | 15:02:10 | 15:03:10 | 15:03:20 | 15:05:10 | 15:06:30 | 255 | 1.0 | 1.8 | 3.2 | |
| 15 | 6 | 23-Mar-99 | 61 | C5 | C5 | T1E-9 | 60 | -12 | -12.0 | 10 | 15:05:35 | 15:06:40 | 15:06:53 | 15:08:00 | 15:09:50 | 332 | 1.1 | 1.1 | 3.0 | |
| 16 | 7 | 23-Mar-99 | 57 | 1 | Aluminum | T1E-9 | 60 | -12 | -12.0 | 10 | 15:10:50 | 15:11:49 | 15:12:05 | 15:14:00 | 15:14:50 | 408 | 1.0 | 1.9 | 2.8 | |
| 17 | 7 | 23-Mar-99 | 60 | C4 | C4 | T1E-9 | 60 | -12 | -12.0 | 10 | 15:08:20 | 15:09:22 | 15:09:27 | 15:11:15 | 15:12:20 | 128 | 1.0 | 1.8 | 2.9 | |
| 18 | 8 | 23-Mar-99 | 52 | 2 | Aluminum | Water | 60 | -12 | -12.0 | 10 | 14:13:38 | 14:14:38 | 14:14:58 | 14:16:15 | 14:17:48 | 510 | 1.0 | 1.3 | 2.8 | double quantity |
| 19 | 8 | 23-Mar-99 | 53 | C1 | C1 | Water | 60 | -12 | -11.9 | 10 | 14:16:05 | 14:17:03 | 14:17:11 | 14:18:15 | 14:18:45 | 204 | 1.0 | 1.1 | 1.6 | |
| 20 | 8 | 23-Mar-99 | 52 | 3 | Aluminum | Water | 60 | -12 | -11.9 | 10 | 14:18:05 | 14:19:10 | 14:19:22 | 14:20:37 | 14:21:45 | 306 | 1.1 | 1.3 | 2.4 | |
| 21 | 9 | 23-Mar-99 | 55 | C4 | C4 | Water | 60 | -12 | -11.9 | 10 | 14:24:00 | 14:25:03 | 14:25:16 | 14:26:00 | 14:28:00 | 332 | 1.1 | 0.7 | 2.7 | |
| 22 | 9 | 23-Mar-99 | 56 | C5 | C5 | Water | 60 | -12 | -11.9 | 10 | 14:32:25 | 14:33:25 | 14:33:31 | 14:34:30 | 14:36:05 | 153 | 1.0 | 1.0 | 2.6 | short spray time |
| 23 | 9 | 23-Mar-99 | 53 | C1 | C1 | Water | 60 | -12 | -11.9 | 10 | 14:35:50 | 14:36:50 | 14:37:01 | 14:38:00 | 14:38:55 | 281 | 1.0 | 1.0 | 1.9 | |
| 24 | 10 | 23-Mar-99 | 54 | C3 | C3 | Water | 60 | -12 | -11.9 | 10 | 14:37:30 | 14:38:30 | 14:38:41 | 14:39:40 | 14:41:05 | 281 | 1.0 | 1.0 | 2.4 | |
| 25 | 11 | 23-Mar-99 | extra | 1 | Aluminum | Water | 60 | -12 | -12.3 | 10 | 16:39:57 | 16:40:57 | 16:41:18 | 16:42:10 | 16:42:45 | 284 | 1.0 | 0.9 | 1.5 | 10 sec--135mL special test with different nozzle |
| 26 | 11 | 23-Mar-99 | extra | 2 | Aluminum | Water | 60 | -12 | -12.3 | 10 | 16:43:30 | 16:44:11 | 16:44:25 | 16:45:10 | 16:46:10 | 386 | 0.7 | 0.8 | 1.8 | 10 sec--275mL; special test different nozzle |
| 27 | 12 | 23-Mar-99 | | 1 | Aluminum | Water | 60 | -12 | -12.2 | 10 | 16:10:53 | 16:11:52 | 16:12:12 | 16:14:02 | 16:14:45 | 510 | 1.0 | 1.8 | 2.6 | double quantity; spray start 20 sec |
| 28 | 12 | 23-Mar-99 | | 2 | Aluminum | Water | 60 | -12 | -12.2 | 10 | 16:12:47 | 16:13:20 | 16:14:00 | 16:16:40 | 16:17:10 | 1020 | 0.6 | 2.7 | 3.2 | spray start 40 sec |
| 29 | 13 | 23-Mar-99 | | 1 | Aluminum | XL54(std) | 60 | -12 | -12.2 | 10 | 15:46:20 | 15:47:26 | 15:47:44 | 15:50:13 | 15:51:30 | 459 | 1.1 | 2.5 | 3.8 | sprayed; special test |
| 30 | 13 | 23-Mar-99 | | 3 | Aluminum | XL54(std) | 60 | -12 | -12.1 | 10 | 16:02:06 | | 16:02:06 | 16:05:10 | 16:06:20 | 500 | 0.0 | 3.1 | 4.2 | poured(bare plate);special test |
| 31 | 13 | 23-Mar-99 | | 1 | Aluminum | XL54(std) | 60 | -12 | -12.2 | 10 | 16:25:40 | 16:27:50 | 16:28:03 | 16:30:22 | 16:31:37 | 332 | 2.2 | 2.3 | 3.6 | sprayed; spray finish-13sec;special test |
| 32 | 14 | 24-Mar-99 | 36 | C5 | C5 | Water | 60 | -9 | -8.8 | 10 | 9:51:42 | 9:52:42 | 9:52:49 | 9:53:30 | 9:55:20 | 179 | 1.0 | 0.7 | 2.5 | |
| 33 | 14 | 24-Mar-99 | 35 | C4 | C4 | Water | 60 | -9 | -8.7 | 10 | 9:55:46 | 9:55:59 | 9:56:08 | 9:57:07 | 9:59:00 | 230 | 0.2 | 1.0 | 2.9 | |
| 34 | 15 | 24-Mar-99 | 32 | 2 | Aluminum | Water | 60 | -9 | -8.7 | 10 | 9:53:05 | 9:54:03 | 9:54:14 | 9:54:55 | 9:56:25 | 281 | 1.0 | 0.7 | 2.2 | |
| 35 | 15 | 24-Mar-99 | 33 | C1 | C1 | Water | 60 | -9 | -8.6 | 10 | 9:54:38 | 9:55:38 | 9:55:49 | 9:56:55 | 9:57:50 | 281 | 1.0 | 1.1 | 2.0 | |
| 36 | 15 | 24-Mar-99 | 32 | 1 | Aluminum | Water | 60 | -9 | -9.1 | 10 | 9:58:08 | 9:59:06 | 9:59:16 | 10:00:40 | 10:01:30 | 255 | 1.0 | 1.4 | 2.2 | |
| 37 | 16 | 24-Mar-99 | 34 | C3 | C3 | Water | 60 | -9 | -9.3 | 10 | 10:00:20 | 10:01:20 | 10:01:30 | 10:03:10 | 10:04:35 | 255 | 1.0 | 1.7 | 3.1 | |
| 38 | 16 | 24-Mar-99 | 33 | C1 | C1 | Water | 60 | -9 | -9.4 | 10 | 10:14:36 | 10:15:36 | 10:15:47 | 10:17:06 | 10:17:46 | 281 | 1.0 | 1.3 | 2.0 | |
| 39 | 16 | 24-Mar-99 | 34 | C3 | C3 | Water | 60 | -9 | -9.4 | 10 | 10:18:43 | 10:19:43 | 10:19:54 | 10:21:10 | 10:22:30 | 281 | 1.0 | 1.3 | 2.6 | |
| 40 | 17 | 24-Mar-99 | | 1 | Aluminum | Water | 60 | -9 | -9.4 | 10 | | 10:15:37 | 10:15:37 | 10:17:15 | 10:18:15 | 500 | 0.0 | 1.6 | 2.6 | no contamination;1/2 liter poured |
| 41 | 18 | 24-Mar-99 | 36 | C5 | C5 | Water | 60 | -9 | -9.4 | 10 | 10:15:45 | 10:16:45 | 10:16:58 | 10:18:56 | 10:19:28 | 332 | 1.0 | 2.0 | 2.5 | |
| 42 | 18 | 24-Mar-99 | 35 | C4 | C4 | Water | 60 | -9 | -9.4 | 10 | 10:17:19 | 10:18:26 | 10:18:36 | 10:19:45 | 10:20:58 | 255 | 1.1 | 1.2 | 2.4 | |
| 43 | 19 | 24-Mar-99 | 32 | 1 | Aluminum | Water | 60 | -9 | -9.4 | 10 | 10:21:30 | 10:22:28 | 10:22:48 | 10:25:03 | 10:25:46 | 510 | 1.0 | 2.3 | 3.0 | 20 sec spray |
| 44 | 20 | 24-Mar-99 | 41 | 6 | C5 | T1E-6 | 60 | -9 | -9.5 | 10 | 11:22:45 | 11:23:45 | 11:23:56 | 11:25:11 | 11:26:17 | 281 | 1.0 | 1.3 | 2.4 | |
| 45 | 20 | 24-Mar-99 | 40 | 4 | C4 | T1E-6 | 60 | -9 | -9.5 | 10 | 11:24:35 | 11:25:35 | 11:25:45 | 11:27:29 | 11:28:00 | 255 | 1.0 | 1.7 | 2.3 | |
| 46 | 21 | 24-Mar-99 | 37 | 1 | Aluminum | T1E-6 | 60 | -9 | -9.3 | 10 | 11:29:40 | 11:30:38 | 11:30:53 | 11:32:53 | 11:33:30 | 383 | 1.0 | 2.0 | 2.6 | |
| 47 | 21 | 24-Mar-99 | 38 | C1 | C1 | T1E-6 | 60 | -9 | -9.4 | 10 | 11:27:32 | 11:28:32 | 11:28:33 | 11:30:01 | 11:31:05 | 26 | 1.0 | 1.5 | 2.5 | low fluid quantity |
| 48 | 21 | 24-Mar-99 | 39 | C3 | C3 | T1E-6 | 60 | -9 | -9.4 | 10 | 11:31:40 | 11:32:39 | 11:32:54 | 11:34:25 | 11:35:25 | 383 | 1.0 | 1.5 | 2.5 | |
| 49 | 22 | 24-Mar-99 | 37 | 2 | Aluminum | T1E-6 | 60 | -9 | -9.4 | 10 | 11:57:17 | 11:58:27 | 11:58:43 | 12:00:31 | 12:01:34 | 408 | 1.2 | 1.8 | 2.9 | |

## TABLE 4-1. HOT WATER DEICING AT NRC – WINTER 1999 (Continued)

| ID # | Form # | Date | Run # | Plate # | Surface Type | Fluid Type | Fluid Temp. (°C) | Ambient Temp (Design) (°C) | Ambient Temp (Actual) (°C) | Wind Speed kph | Plate Expos. Time | Spray Start Time | Spray Finish Time | Time of 1st Freeze | Time of Failure | Fluid Qty. (ml) | Exposure Interval (min) | Interval to 1st Freeze (min) | Interval to Complete Failure (min) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 22 | 24-Mar-99 | 38 | C1 | C1 | T1E-6 | 60 | -9 | -9.6 | 10 | 11:50:57 | 11:51:58 | 11:52:11 | 11:53:16 | 11:54:20 | 332 | 1.0 | 1.1 | 2.2 | |
| 51 | 22 | 24-Mar-99 | 39 | C3 | C3 | T1E-6 | 60 | -9 | -9.4 | 10 | 11:53:35 | 11:54:32 | 11:54:44 | 11:56:20 | 11:57:35 | 306 | 1.0 | 1.6 | 2.9 | |
| 52 | 23 | 24-Mar-99 | 40 | C4 | C4 | T1E-6 | 60 | -9 | -9.4 | 10 | 11:57:11 | 11:58:11 | 11:58:26 | 11:59:48 | 12:00:56 | 383 | 1.0 | 1.4 | 2.5 | |
| 53 | 23 | 24-Mar-99 | 41 | C5 | C5 | T1E-6 | 60 | -9 | -9.4 | 10 | 11:59:32 | 12:00:32 | 12:00:49 | 12:01:59 | 12:02:47 | 434 | 1.0 | 1.2 | 2.0 | |
| 54 | 24 | 24-Mar-99 | | 3 | Aluminum | T1E-6 | 60 | -9 | -9.5 | 10 | 12:10:16 | 12:15:16 | 12:15:37 | 12:16:58 | 12:18:22 | 536 | 5.0 | 1.4 | 2.8 | 5 min exposure time for plate |
| 55 | 24 | 24-Mar-99 | | 2 | Aluminum | XL54(std) | 60 | -9 | -9.4 | 10 | 12:21:55 | 12:22:55 | 12:22:55 | 12:25:41 | 12:26:41 | 500 | 1.0 | 2.8 | 3.8 | poured |
| 56 | 25 | 24-Mar-99 | | 1 | Aluminum | XL54(std) | 60 | -9 | -9.6 | 10 | 12:35:15 | 12:36:15 | 12:36:30 | 12:38:45 | 12:40:20 | 383 | 1.0 | 2.3 | 3.8 | |
| 57 | 25 | 24-Mar-99 | | 3 | Aluminum | XL54(std) | 60 | -9 | -9.5 | 10 | 12:38:21 | 12:39:21 | 12:39:41 | 12:42:45 | 12:43:38 | 510 | 1.0 | 3.1 | 4.0 | |
| 58 | 25 | 24-Mar-99 | | 2 | Aluminum | XL54(std) | 60 | -9 | -9.5 | 10 | 12:40:16 | 12:41:16 | 12:41:56 | 12:45:30 | 12:47:10 | 1020 | 1.0 | 3.6 | 5.2 | |
| 59 | 26 | 24-Mar-99 | 29 | 1 | Aluminum | Water | 60 | -9 | -9.6 | 0 | 12:59:39 | 13:00:39 | 13:00:47 | 13:02:12 | 13:04:05 | 204 | 1.0 | 1.4 | 3.3 | |
| 60 | 26 | 24-Mar-99 | 30 | 2 | Aluminum | T1E-6 | 60 | -9 | -9.9 | 0 | 13:11:25 | 13:12:25 | 13:12:39 | 13:14:48 | 13:16:21 | 357 | 1.0 | 2.2 | 3.7 | |
| 61 | 26 | 24-Mar-99 | 29 | 3 | Aluminum | Water | 60 | -9 | -9.6 | 0 | 13:01:12 | 13:02:12 | 13:02:25 | 13:03:21 | 13:06:08 | 332 | 1.0 | 0.9 | 3.7 | |
| 62 | 27 | 24-Mar-99 | 30 | 1 | Aluminum | T1E-6 | 60 | -9 | -10.0 | 0 | 13:21:24 | 13:22:24 | 13:22:41 | 13:24:30 | 13:26:10 | 434 | 1.0 | 1.8 | 3.5 | |
| 63 | 28 | 24-Mar-99 | 9 | 2 | Aluminum | Water | 60 | -6 | -6.0 | 0 | 14:05:40 | 14:06:39 | 14:06:50 | 14:10:20 | 14:11:35 | 281 | 1.0 | 3.5 | 4.8 | |
| 64 | 28 | 24-Mar-99 | 10 | 2 | Aluminum | T1E-3 | 60 | -6 | -6.3 | 0 | 14:24:30 | 14:25:30 | 14:25:44 | 14:28:51 | 14:30:15 | 357 | 1.0 | 3.1 | 4.5 | |
| 65 | 29 | 24-Mar-99 | 9 | 1 | Aluminum | Water | 60 | -6 | -6.3 | 0 | 14:07:00 | 14:08:00 | 14:08:09 | 14:10:49 | 14:12:20 | 230 | 1.0 | 2.7 | 4.2 | |
| 66 | 29 | 24-Mar-99 | 10 | 1 | Aluminum | T1E-3 | 60 | -6 | -6.3 | 0 | 14:26:10 | 14:27:10 | 14:27:21 | 14:29:40 | 14:31:27 | 281 | 1.0 | 2.3 | 4.1 | |
| 67 | 30 | 24-Mar-99 | 17 | 2 | Aluminum | T1E-3 | 60 | -6 | -6.0 | 10 | 14:55:50 | 14:56:53 | 14:57:07 | 14:59:07 | 15:00:30 | 357 | 1.1 | 2.0 | 3.4 | |
| 68 | 30 | 24-Mar-99 | 18 | C1 | C1 | T1E-3 | 60 | -6 | -6.0 | 10 | 14:58:27 | 14:59:25 | 14:59:36 | 15:01:10 | 15:02:10 | 281 | 1.0 | 1.6 | 2.6 | |
| 69 | 30 | 24-Mar-99 | 19 | C3 | C3 | T1E-3 | 60 | -6 | -6.0 | 10 | 14:59:55 | 15:00:57 | 15:01:07 | 15:02:52 | 15:03:50 | 255 | 1.0 | 1.8 | 2.7 | |
| 70 | 31 | 24-Mar-99 | 17 | 3 | Aluminum | T1E-3 | 60 | -6 | -6.0 | 10 | 15:05:00 | 15:06:01 | 15:06:12 | 15:07:57 | 15:09:12 | 281 | 1.0 | 1.8 | 3.0 | |
| 71 | 31 | 24-Mar-99 | 18 | C1 | C1 | T1E-3 | 60 | -6 | -6.1 | 10 | 15:39:15 | 15:40:15 | 15:40:25 | 15:42:00 | 15:43:07 | 255 | 1.0 | 1.6 | 2.7 | |
| 72 | 31 | 24-Mar-99 | 19 | C3 | C3 | T1E-3 | 60 | -6 | -6.0 | 10 | 15:41:45 | 15:42:46 | 15:42:54 | 15:44:28 | 15:45:22 | 204 | 1.0 | 1.6 | 2.5 | |
| 73 | 32 | 24-Mar-99 | 12 | 1 | Aluminum | Water | 60 | -6 | -5.9 | 10 | 15:16:27 | 15:17:25 | 15:17:37 | 15:19:45 | 15:20:45 | 306 | 1.0 | 2.1 | 3.1 | |
| 74 | 32 | 24-Mar-99 | 13 | C1 | C1 | Water | 60 | -6 | -6.0 | 10 | 15:28:00 | 15:29:00 | 15:29:11 | 15:30:45 | 15:31:57 | 281 | 1.0 | 1.6 | 2.8 | |
| 75 | 32 | 24-Mar-99 | 14 | C3 | C3 | Water | 60 | -6 | -6.0 | 10 | 15:29:25 | 15:30:21 | 15:30:30 | 15:32:25 | 15:34:07 | 230 | 0.9 | 1.9 | 3.6 | |
| 76 | 33 | 24-Mar-99 | 20 | 3 | C4 | T1E-3 | 60 | -6 | -6.0 | 10 | 15:46:10 | 15:47:10 | 15:47:18 | 15:48:56 | 15:49:57 | 204 | 1.0 | 1.6 | 2.7 | |
| 77 | 33 | 24-Mar-99 | 21 | 2 | C5 | T1E-3 | 60 | -6 | -6.0 | 10 | 15:45:40 | 15:46:40 | 15:46:42 | 15:48:20 | 15:49:24 | 51 | 1.0 | 1.6 | 2.7 | low fluid quantity |
| 78 | 34 | 24-Mar-99 | 20 | C4 | C4 | T1E-3 | 60 | -6 | -6.0 | 10 | 14:57:14 | 14:58:15 | 14:58:22 | 15:00:42 | 15:01:10 | 179 | 1.0 | 2.3 | 2.8 | |
| 79 | 34 | 24-Mar-99 | 21 | 2 | C5 | T1E-3 | 60 | -6 | -6.0 | 10 | 15:03:30 | 15:04:30 | 15:04:38 | 15:06:08 | 15:07:12 | 204 | 1.0 | 1.5 | 2.6 | |
| 80 | 35 | 24-Mar-99 | 12 | 2 | Aluminum | Water | 60 | -6 | -5.9 | 10 | 15:10:46 | 15:11:53 | 15:12:06 | 15:14:27 | 15:15:15 | 332 | 1.1 | 2.4 | 3.2 | |
| 81 | 35 | 24-Mar-99 | 13 | C1 | C1 | Water | 60 | -6 | -5.9 | 10 | 15:14:11 | 15:15:10 | 15:15:20 | 15:16:56 | 15:18:05 | 255 | 1.0 | 1.6 | 2.8 | |
| 82 | 35 | 24-Mar-99 | 14 | C3 | C3 | Water | 60 | -6 | -6.0 | 10 | 16:02:25 | 16:03:25 | 16:03:37 | 16:05:43 | 16:07:12 | 306 | 1.0 | 2.1 | 3.6 | |
| 83 | 36 | 24-Mar-99 | 15 | C4 | C4 | Water | 60 | -6 | -6.0 | 10 | 15:29:30 | 15:30:32 | 15:30:41 | 15:31:47 | 15:33:25 | 230 | 1.0 | 1.1 | 2.7 | |
| 84 | 36 | 24-Mar-99 | 16 | C5 | C5 | Water | 60 | -6 | -6.0 | 10 | 15:28:11 | 15:29:11 | 15:29:18 | 15:30:15 | 15:32:08 | 179 | 1.0 | 1.0 | 2.8 | |
| 85 | 37 | 24-Mar-99 | | 3 | Aluminum | T1E-3 | 60 | -6 | -6.0 | 10 | 15:47:30 | 15:48:30 | 15:48:50 | 15:51:18 | 15:52:27 | 510 | 1.0 | 2.5 | 3.6 | special test 20 sec spray |
| 86 | 37 | 24-Mar-99 | | 2 | Aluminum | Water | 60 | -6 | -6.0 | 10 | 15:51:34 | 15:52:33 | 15:52:53 | 15:55:35 | 15:56:21 | 510 | 1.0 | 2.7 | 3.5 | special test 20 sec spray |
| 87 | 38 | 24-Mar-99 | 15 | C4 | C4 | Water | 60 | -6 | -6.0 | 10 | 16:04:15 | 16:05:15 | 16:05:22 | 16:06:02 | 16:08:28 | 179 | 1.0 | 0.7 | 3.1 | |
| 88 | 38 | 24-Mar-99 | 16 | C5 | C5 | Water | 60 | -6 | -6.0 | 10 | 16:02:58 | 16:03:58 | 16:04:07 | 16:05:40 | 16:07:26 | 230 | 1.0 | 1.6 | 3.3 | |
| 89 | 39 | 24-Mar-99 | | 3 | Aluminum | XL54(std) | 60 | -6 | -6.0 | 10 | 16:30:00 | 16:31:01 | 16:31:13 | 16:33:56 | 16:36:00 | 306 | 1.0 | 2.7 | 4.8 | |
| 90 | 40 | 24-Mar-99 | | 1 | Aluminum | XL54(std) | 60 | -6 | -6.0 | 10 | 16:27:20 | 16:28:20 | 16:28:38 | 16:31:40 | 16:33:18 | 459 | 1.0 | 3.0 | 4.7 | spray |
| 91 | 40 | 24-Mar-99 | | 2 | Aluminum | XL54(std) | 60 | -6 | -5.9 | 10 | | 16:42:20 | 16:42:29 | 16:46:49 | 16:47:25 | 500 | 0.0 | 4.3 | 4.9 | poured, bare plate |
| 92 | 41 | 24-Mar-99 | 24 | 3 | Aluminum | T1E-3 | 60 | -6 | -5.9 | 20 | 17:24:07 | 17:25:18 | 17:25:29 | 17:26:57 | 17:28:09 | 281 | 1.2 | 1.5 | 2.7 | |
| 93 | 41 | 24-Mar-99 | 23 | 1 | Aluminum | Water | 60 | -6 | -5.9 | 20 | 17:26:22 | 17:27:29 | 17:27:39 | 17:29:09 | 17:30:00 | 255 | 1.1 | 1.5 | 2.4 | |
| 94 | 42 | 24-Mar-99 | 24 | 2 | Aluminum | T1E-3 | 60 | -6 | -5.9 | 20 | 17:24:06 | 17:25:08 | 17:25:16 | 17:27:04 | 17:28:01 | 204 | 1.0 | 1.8 | 2.8 | |
| 95 | 42 | 24-Mar-99 | 23 | 2 | Aluminum | Water | 60 | -6 | -5.9 | 20 | 17:33:10 | 17:34:10 | 17:34:21 | 17:36:05 | 17:36:59 | 281 | 1.0 | 1.7 | 2.6 | |
| 96 | 43 | 25-Mar-99 | 1 | 2 | Aluminum | Water | 60 | -3 | -2.9 | 0 | 9:16:30 | 9:17:30 | 9:17:42 | 9:24:04 | 9:25:27 | 306 | 1.0 | 6.4 | 7.8 | |
| 97 | 43 | 25-Mar-99 | 1 | 1 | Aluminum | Water | 60 | -3 | -3.0 | 0 | 9:29:50 | 9:30:50 | 9:31:01 | 9:35:40 | 9:37:16 | 281 | 1.0 | 4.7 | 6.3 | |
| 98 | 44 | 25-Mar-99 | 1 | 3 | Aluminum | Water | 60 | -3 | -2.9 | 0 | 9:16:30 | 9:17:53 | 9:18:04 | 9:24:22 | 9:25:40 | 281 | 1.4 | 6.3 | 7.6 | |
| 99 | 44 | 25-Mar-99 | | 2 | Aluminum | Water | 60 | -3 | -3.0 | 0 | 9:32:00 | 9:37:25 | 9:37:37 | 9:43:18 | 9:44:15 | 306 | 5.4 | 5.7 | 6.6 | exposed for 5 min |

## TABLE 4-1. HOT WATER DEICING AT NRC – WINTER 1999 (Continued)

| ID # | Form # | Date | Run # | Plate # | Surface Type | Fluid Type | Fluid Temp. (°C) | Ambient Temp (Design) (°C) | Ambient Temp (Actual) (°C) | Wind Speed kph | Plate Expos. Time | Spray Start Time | Spray Finish Time | Time of 1st Freeze | Time of Failure | Fluid Qty. (ml) | Exposure Interval (min) | Interval to 1st Freeze (min) | Interval to Complete Failure (min) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 44 | 25-Mar-99 | | 3 | Aluminum | Water | 60 | -3 | -3.0 | 0 | 9:41:50 | 10:09:12 | 10:09:30 | 10:15:03 | 10:17:04 | 459 | 10.0 | 5.6 | 7.6 | plate exposed till 9:51:50; 10 min |
| 101 | 45 | 25-Mar-99 | | 2 | Aluminum | Water | 60 | -3 | -2.9 | 0 | 10:22:07 | 10:23:12 | 10:23:20 | 10:30:55 | 10:32:30 | 500 | 1.1 | 7.6 | 9.2 | poured; special test— contamination 1 1/2 min |
| 102 | 46 | 25-Mar-99 | 1 | 1 | Aluminum | Water | 60 | -3 | -3.0 | 0 | 10:07:07 | 10:07:07 | 10:07:13 | 10:15:21 | 10:17:03 | 500 | 0.0 | 8.1 | 9.8 | poured, bare plate |
| 103 | 47 | 25-Mar-99 | 2 | 2 | Aluminum | Water | 60 | -3 | -2.6 | 10 | 10:58:35 | 10:59:35 | 10:59:43 | 11:02:39 | 11:03:30 | 204 | 1.0 | 2.9 | 3.8 | |
| 104 | 47 | 25-Mar-99 | 4 | C3 | C3 | Water | 60 | -3 | -2.6 | 10 | 10:59:57 | 11:00:58 | 11:01:05 | 11:03:52 | 11:06:00 | 179 | 1.0 | 2.8 | 4.9 | |
| 105 | 47 | 25-Mar-99 | 3 | C1 | C1 | Water | 60 | -3 | -2.5 | 10 | 11:05:45 | 11:06:44 | 11:06:56 | 11:09:28 | 11:10:30 | 306 | 1.0 | 2.5 | 3.6 | |
| 106 | 48 | 25-Mar-99 | 5 | C4 | C4 | Water | 60 | -3 | -2.6 | 10 | 10:58:45 | 10:59:45 | 10:59:52 | 11:03:28 | 11:04:16 | 179 | 1.0 | 3.6 | 4.4 | |
| 107 | 48 | 25-Mar-99 | 6 | C5 | C5 | Water | 60 | -3 | -2.5 | 10 | 11:00:10 | 11:01:10 | 11:01:15 | 11:03:42 | 11:05:34 | 128 | 1.0 | 2.5 | 4.3 | |
| 108 | 49 | 25-Mar-99 | | 2 | Aluminum | Water | 60 | -3 | -2.5 | 10 | 11:33:06 | 11:34:08 | 11:34:15 | 11:37:45 | 11:39:40 | 500 | 1.0 | 3.5 | 5.4 | poured contaminated 1/2 liter |
| 109 | 50 | 25-Mar-99 | 5 | C4 | C4 | Water | 60 | -3 | -2.4 | 10 | 11:52:25 | 11:53:25 | 11:53:32 | 11:56:11 | 11:57:58 | 179 | 1.0 | 2.7 | 4.4 | |
| 110 | 50 | 25-Mar-99 | 6 | C5 | C5 | Water | 60 | -3 | -2.4 | 10 | 11:50:09 | 11:51:09 | 11:51:14 | 11:53:41 | 11:56:05 | 128 | 1.0 | 2.5 | 4.9 | |
| 111 | 50 | 25-Mar-99 | | 3 | Aluminum | Water | 60 | -3 | -2.4 | 10 | | 11:47:20 | 11:47:28 | 11:51:48 | 11:53:11 | 500 | 0.0 | 4.3 | 5.7 | poured, bare plate |
| 112 | 51 | 25-Mar-99 | 2 | 3 | Aluminum | Water | 60 | -3 | -2.5 | 10 | 11:08:20 | 11:09:20 | 11:09:30 | 11:12:50 | 11:14:10 | 255 | 1.0 | 3.3 | 4.7 | |
| 113 | 51 | 25-Mar-99 | 3 | C1 | C1 | Water | 60 | -3 | -2.4 | 10 | 11:48:10 | 11:49:10 | 11:49:11 | 11:51:55 | 11:52:55 | 26 | 1.0 | 2.7 | 3.7 | |
| 114 | 51 | 25-Mar-99 | 4 | C3 | C3 | Water | 60 | -3 | -2.5 | 10 | 12:04:10 | 12:05:10 | 12:05:16 | 12:08:20 | 12:10:20 | 153 | 1.0 | 3.1 | 5.1 | |
| 115 | 52 | 25-Mar-99 | 7 | 2 | Aluminum | Water | 60 | -3 | -2.4 | 20 | 12:40:11 | 12:41:11 | 12:41:21 | 12:44:36 | 12:45:11 | 255 | 1.0 | 3.3 | 3.8 | |
| 116 | 52 | 25-Mar-99 | 7 | 3 | Aluminum | Water | 60 | -3 | -2.4 | 20 | 12:40:41 | 12:41:41 | 12:41:48 | 12:44:42 | 12:45:58 | 179 | 1.0 | 2.9 | 4.2 | |
| 117 | 53 | 25-Mar-99 | 8 | 2 | Aluminum | Water | 60 | -3 | -2.3 | 30 | 14:08:07 | 14:09:06 | 14:09:17 | 14:12:35 | 14:13:35 | 281 | 1.0 | 3.3 | 4.3 | |
| 118 | 54 | 25-Mar-99 | 8 | 3 | Aluminum | Water | 60 | -3 | -2.2 | 30 | 14:09:09 | 14:10:20 | 14:10:36 | 14:13:09 | 14:14:21 | 408 | 1.2 | 2.6 | 3.8 | fluid application was stopped (3-4 sec) to adjust unit |
| 119 | 55 | 25-Mar-99 | 903 | 2 | Aluminum | Water | 60 | -9 | -9.2 | 0 | 15:41:56 | 15:42:56 | 15:43:19 | 15:45:40 | 15:46:40 | 587 | 1.0 | 2.4 | 3.4 | 23 sec spray, suspect heavy ice deposit while chamber cooled |
| 120 | 55 | 25-Mar-99 | 905 | 1 | Aluminum | Water | 60 | -9 | -9.1 | 0 | 15:43:36 | 15:44:36 | 15:44:56 | 15:49:00 | 15:49:42 | 510 | 1.0 | 4.1 | 4.8 | 20 sec spray |
| 121 | 56 | 25-Mar-99 | 904 | 3 | Aluminum | Water | 60 | -9 | -9.2 | 0 | 15:41:59 | 15:43:10 | 15:43:18 | 15:44:27 | 15:47:07 | 204 | 1.2 | 1.2 | 3.8 | regular spray |
| 122 | 56 | 25-Mar-99 | 906 | 1 | Aluminum | Water | 60 | -9 | -9.3 | 0 | 16:05:50 | 16:06:50 | 16:07:30 | 16:12:46 | 16:13:30 | 1020 | 1.0 | 5.3 | 6.0 | 40 sec spray |
| 123 | 56 | 25-Mar-99 | 904 | 2 | Aluminum | Water | 60 | -9 | -9.2 | 0 | 16:08:02 | 16:09:02 | 16:09:15 | 16:11:42 | 16:13:00 | 332 | 1.0 | 2.5 | 3.8 | |
| 124 | 57 | 25-Mar-99 | 903 | 3 | Aluminum | Water | 60 | -9 | -9.3 | 0 | 16:06:40 | 16:07:42 | 16:07:53 | 16:09:45 | 16:11:50 | 281 | 1.0 | 1.9 | 4.0 | regular spray |
| 125 | 57 | 25-Mar-99 | 905 | 3 | Aluminum | Water | 60 | -9 | -9.6 | 0 | 16:29:50 | 16:30:50 | 16:31:10 | 16:36:10 | 16:36:22 | 510 | 1.0 | 5.0 | 5.2 | 20 sec spray |
| 126 | 58 | 25-Mar-99 | 907 | 2 | Aluminum | T1E-6 | 60 | -9 | -9.5 | 0 | 16:34:25 | 16:35:25 | 16:35:36 | 16:38:17 | 16:39:58 | 281 | 1.0 | 2.7 | 4.4 | |
| 127 | 58 | 25-Mar-99 | 908 | 1 | Aluminum | T1E-6 | 60 | -9 | -9.5 | 0 | 16:35:48 | 16:36:48 | 16:36:58 | 16:38:59 | 16:40:48 | 255 | 1.0 | 2.0 | 3.8 | |
| 128 | 59 | 25-Mar-99 | 902 | C1 | Aluminum | Water | 60 | -9 | -9.4 | 0 | 16:40:00 | 16:41:00 | 16:41:05 | 16:45:35 | 16:46:20 | 500 | 1.0 | 4.5 | 5.3 | poured 1/2 liter on contaminated plate; no fluid bottom right corner; C1 sensor used |
| 129 | 59 | 25-Mar-99 | 901 | C3 | Aluminum | Water | 60 | -9 | -9.8 | 0 | | 16:58:05 | 16:58:13 | 17:01:40 | 17:02:47 | 500 | 0.0 | 3.5 | 4.6 | pour on bare plate; fluid did not reach left side of plate(dry); C3 sensor used |
| 130 | 60 | 25-Mar-99 | 916 | 2 | Aluminum | T1E-6 | 60 | -9 | -9.2 | 10 | 17:27:56 | 17:28:58 | 17:29:10 | 17:30:45 | 17:32:00 | 306 | 1.0 | 1.6 | 2.8 | |
| 131 | 60 | 25-Mar-99 | 910 | 1 | Aluminum | Water | 60 | -9 | -8.8 | 10 | 17:34:40 | 17:35:40 | 17:35:40 | 17:37:30 | 17:38:35 | 500 | 1.0 | 1.8 | 2.9 | pour 1/2 liter on contaminated plate; ignore bottom right edge |
| 132 | 61 | 25-Mar-99 | 911 | C1 | Aluminum | Water | 60 | -9 | -8.7 | 10 | 17:48:50 | 17:49:55 | 17:50:08 | 17:51:53 | 17:52:20 | 332 | 1.1 | 1.8 | 2.2 | |
| 133 | 61 | 25-Mar-99 | 912 | C3 | Aluminum | Water | 60 | -9 | -8.8 | 10 | 17:50:10 | 17:52:01 | 17:52:12 | 17:53:47 | 17:54:20 | 281 | 1.9 | 1.6 | 2.1 | |
| 134 | 62 | 25-Mar-99 | 915 | 3 | Aluminum | T1E-6 | 60 | -9 | -9.1 | 10 | 17:39:15 | 17:40:15 | 17:40:30 | 17:42:48 | 17:43:37 | 383 | 1.0 | 2.3 | 3.1 | |
| 135 | 62 | 25-Mar-99 | 913 | 2 | Aluminum | Water | 60 | -9 | -8.9 | 10 | 17:53:20 | 17:54:20 | 17:54:40 | 17:56:38 | 17:57:25 | 510 | 1.0 | 2.0 | 2.8 | 20 sec spray |
| 136 | 63 | 25-Mar-99 | 917 | 2 | Aluminum | Water | 60 | -9 | -8.9 | 20 | 18:15:52 | 18:16:52 | 18:17:06 | 18:17:55 | 18:18:54 | 357 | 1.0 | 0.8 | 1.8 | |
| 137 | 63 | 25-Mar-99 | 918 | 3 | Aluminum | Water | 60 | -9 | -8.9 | 20 | 18:16:05 | 18:17:14 | 18:17:26 | 18:18:02 | 18:19:10 | 306 | 1.2 | 0.6 | 1.7 | |
| 138 | 64 | 25-Mar-99 | 919 | 1 | Aluminum | T1E-6 | 60 | -9 | -8.7 | 20 | 18:20:45 | 18:21:15 | 18:21:35 | 18:23:36 | 18:24:00 | 510 | 0.5 | 2.0 | 2.4 | |
| 139 | 64 | 25-Mar-99 | 920 | 1 | Aluminum | T1E-6 | 60 | -9 | -8.7 | 20 | 18:21:17 | 18:22:17 | 18:22:29 | 18:24:10 | 18:24:55 | 306 | 1.0 | 1.7 | 2.4 | |

**Note**: - Fluid type code T1E-3 denotes Type I fluid, ethylene glycol-based, freeze point of -3°C
- All tests were exposed to Freezing Rain Precipitation (25 g/dm²/hr)

**Legend:** Aluminum Al
Aluminum Honey Comb
Carbon Fibre on Honey Comb
Glass Fibre on Honey Comb
Kevlar on Honey Comb

- Time of Total Plate Failure – is the time when the plate surface is completely covered with ice.

- Fluid Quantity – is a calculated value based on spray duration and sprayer flow rates.

- Exposure Interval – The time differential between the start of plate exposure and the spray start time is the total duration of plate exposure to precipitation prior to testing.

- Interval to 1st Freeze – the elapsed time from spray application to the first observation of the onset of freezing.

- Interval to Complete Failure – the elapsed time from spray application until the complete plate surface has been covered with frozen fluid.

- Comments – describe point of interest or any modifications to test parameters.

## 4.2 DESCRIPTION OF DATA COLLECTED AND ANALYSIS.

The log of tests (table 4-1) incorporates all-important data recorded. Of prime interest is the time interval until the onset of freezing following spray application.

Concentration of Type I fluid as it progressively dilutes under the freezing rain precipitation is also important. Figure 4-1 provides a sample of a completed form showing progressive Brix values and corresponding time.

Temperature profiles of test plate surfaces is the other key element, and provides a basis of inferring the significance of a fluid freeze point value at any point in time. This data was continuously logged in a database.

Data was analyzed by grouping selected tests and presenting them in two main chart types.

The first type of chart plots the time interval from fluid application until first freezing, versus OAT. These charts give an indication of the relationship between time intervals and OAT values, and provide an overall appreciation of values of time intervals observed. Figure 4-2 is a sample of that type of chart.

The second type of chart plots temperature and fluid freeze point profiles of selected runs. This chart type enables a better understanding and comparison of the time for test surfaces to cool under various test conditions, and graphically displays the differential between fluid freeze point and surface temperature as it diminishes with time. Figure 4-3 is a sample of that type of chart.

**DATE:** 23-Mar-99

**OAT:** -12 °C

| | RH (%) | Wind Speed (kph) | | | |
|---|---|---|---|---|---|
| | | Top Left | Top Right | Bottom Left | Bottom Right |
| Start | - | 10 | 10 | 10 | 10 |
| End | - | 10 | 10 | 10 | 10 |

---

**Plate Position:** 4

**Run #:** 62

**Surface Type:** Aluminum

**Fluid Type:** T1E (-9)

**Fluid Brix:** 14 °

**Fluid Temperature:** 60 °

**Plate Exposure Start Time:** (hh:mm:ss)

**Spray Start Time** 14:59:47 (hh:mm:ss)

**Spray Finish time** 15:00:03 (hh:mm:ss)

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | 15:00:14 | 15:00:33 | 15:00:48 | 15:01:02 | 15:01:32 | 15:02:09 | 15:02:30 | 15:02:41 | 15:03:09 | |
| Brix | 15 | 10.5 | 10.75 | 10 | 9.5 | 7.5 | 5.75 | 5.75 | 5 | |
| | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| Time (min) | | | | | | | | | | |
| Brix | | | | | | | | | | |

**Comments on Final Plate Condition:**

**MEASUREMENTS BY:**

**HANDWRITTEN BY:**

FIGURE 4-1. HOT WATER TRIALS – BRIX PROGRESSION

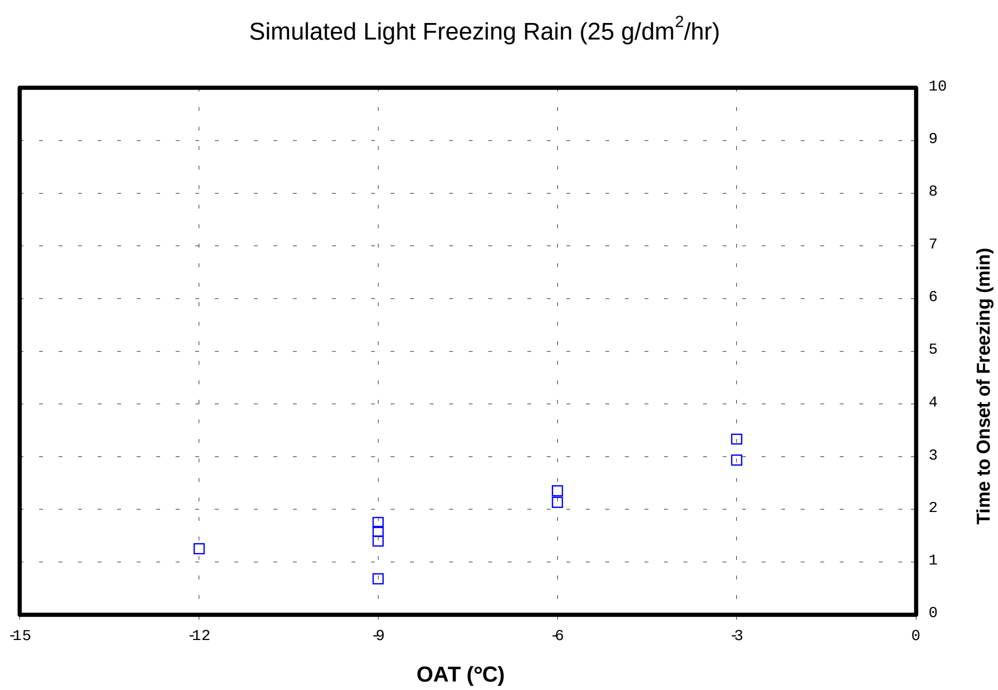
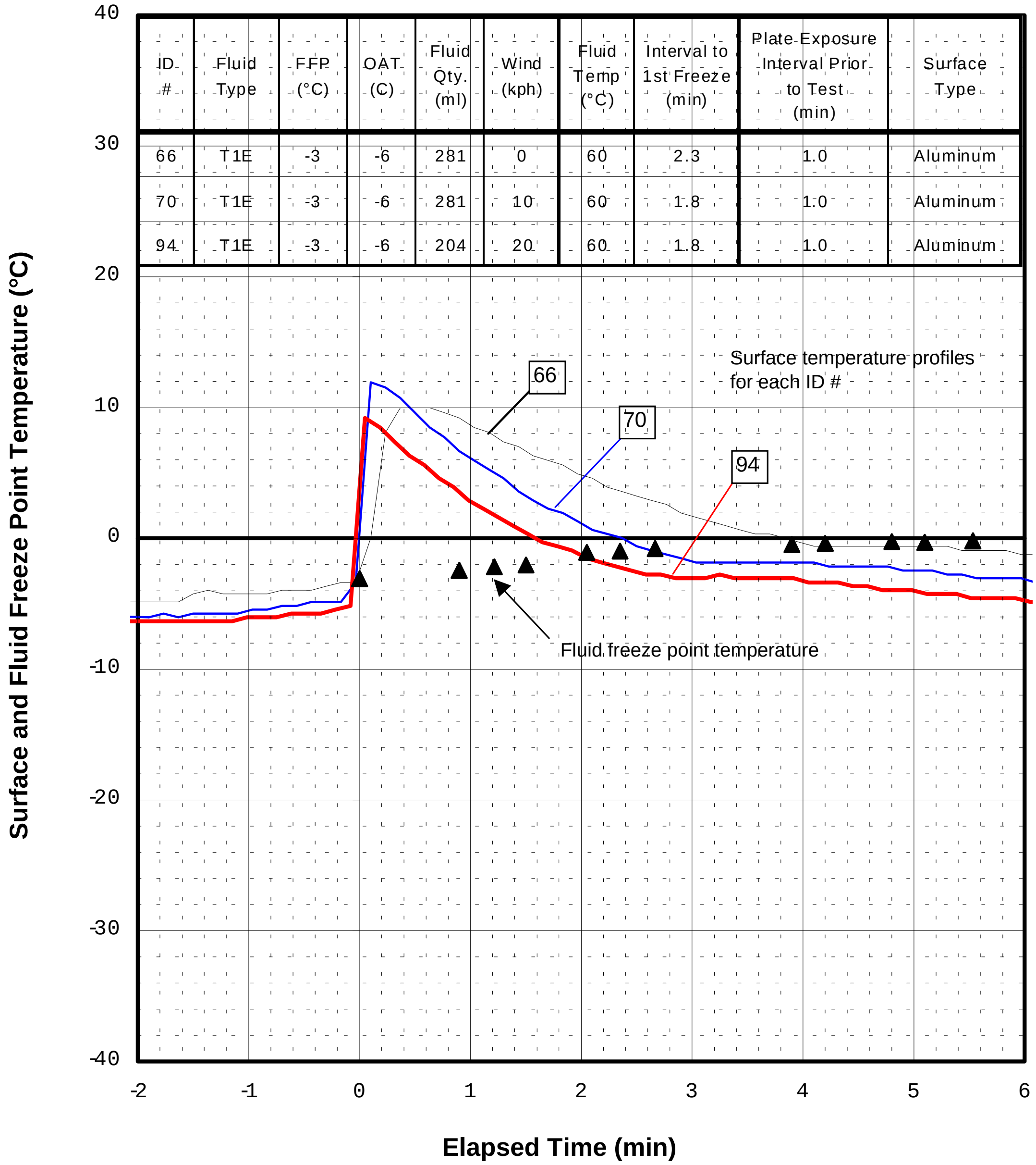



FIGURE 4-2. ELAPSED TIME TO ONSET OF FREEZING, HOT WATER, WINDS 10 kph

**Simulated Light Freezing Rain (25 g/dm²/hr)**
**ID# 66, 70, & 94**




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 66 | T1E | -3 | -6 | 281 | 0 | 60 | 2.3 | 1.0 | Aluminum |
| 70 | T1E | -3 | -6 | 281 | 10 | 60 | 1.8 | 1.0 | Aluminum |
| 94 | T1E | -3 | -6 | 204 | 20 | 60 | 1.8 | 1.0 | Aluminum |

FIGURE 4-3. EFFECT OF WIND AT OAT = -6ºC, HOT TYPE I, SIMULATED LIGHT FREEZING RAIN

## 5. ANALYSIS AND OBSERVATIONS.

This section discusses the results of the various tests. The key measure of performance is the value of the elapsed time from fluid application to the onset of freezing. These values are compared for various test conditions.

The discussion first examines test results from the perspective of constituting a database from which a guideline for application of hot water can be developed. The effect of OAT, wind speed, and test surface composition are considered. The performance of hot water is compared to hot Type I fluid (both diluted and neat).

Test procedures are then examined to detect whether the test design had any significant influence on test results. This examination considers the extent to which test surfaces were allowed to develop contamination, the duration and amount of fluid sprayed, and the method of fluid application (spray versus pour).

### 5.1 ELAPSED TIME TO ONSET OF FREEZING.

For the application of hot water, the relationship between elapsed time to the onset of freezing and OAT for various wind speeds is charted in figures 5-1 to 5-4. In figures 5-5 to 5-7 the corresponding data are presented for dilute Type I fluid, and figure 5-8 presents the results obtained using neat Type I (XL54) fluid.

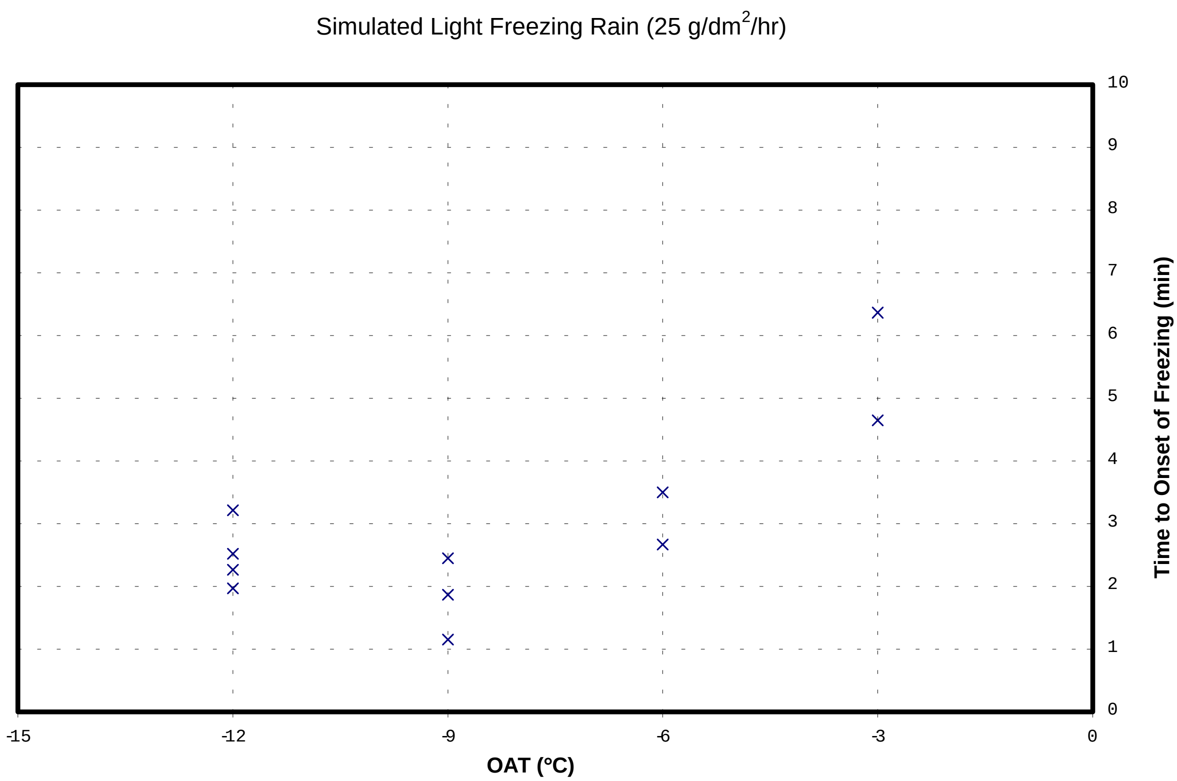



FIGURE 5-1. ELAPSED TIME TO ONSET OF FREEZING – HOT WATER, CALM WINDS

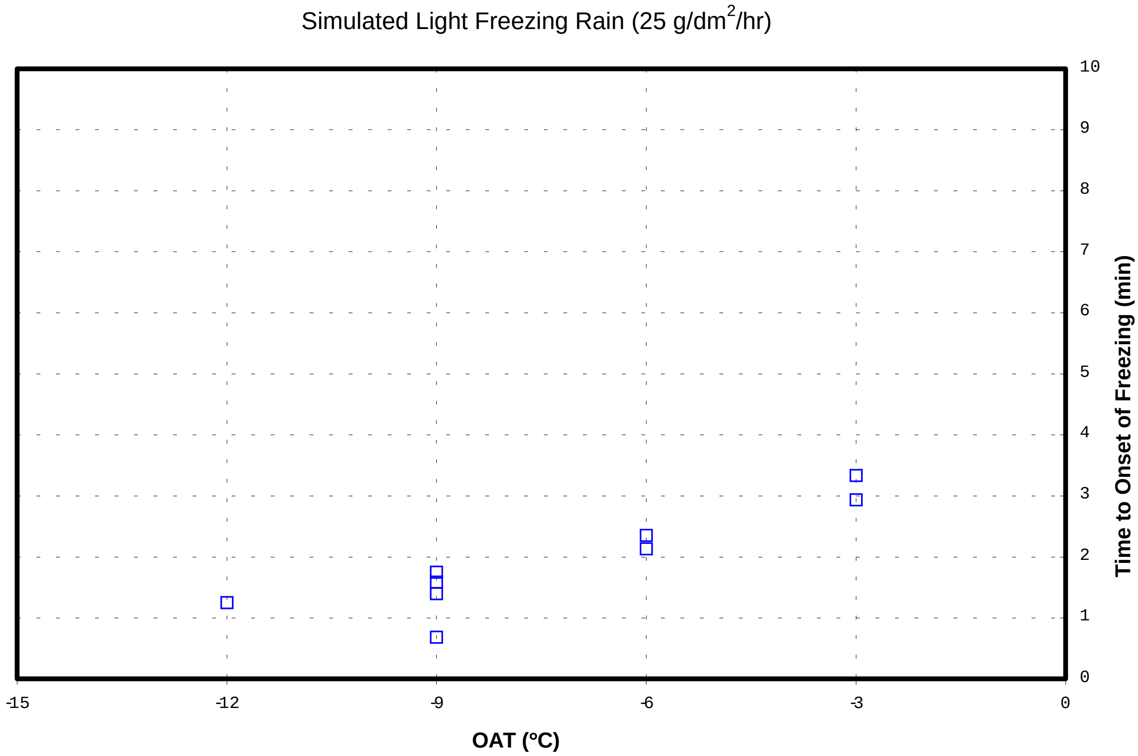



FIGURE 5-2. ELAPSED TIME TO ONSET OF FREEZING – HOT WATER, WINDS 10 kph

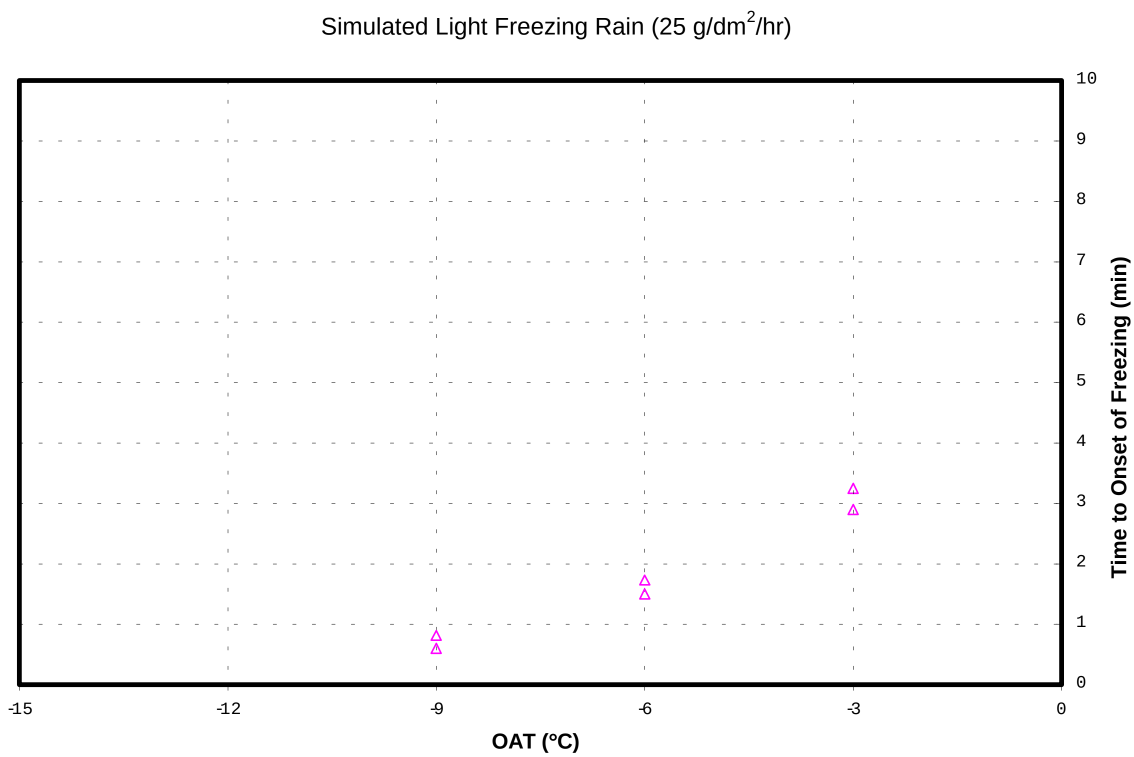



FIGURE 5-3. ELAPSED TIME TO ONSET OF FREEZING – HOT WATER, WINDS 20 kph

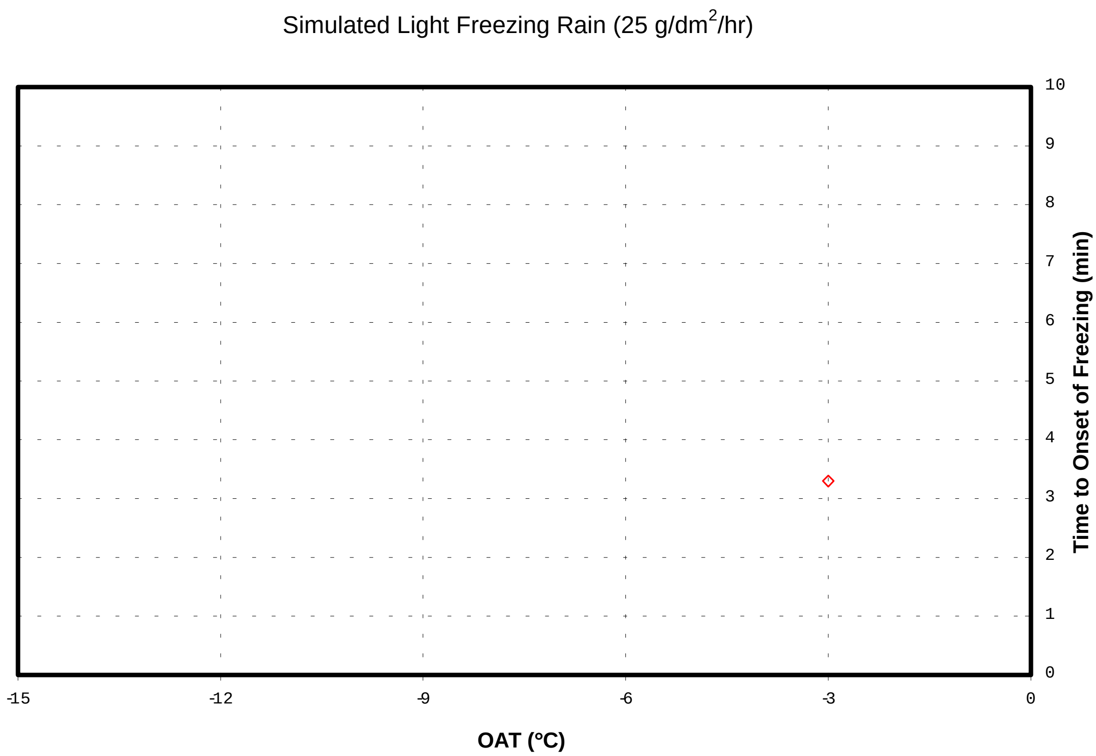



FIGURE 5-4. ELAPSED TIME TO ONSET OF FREEZING – HOT WATER, WINDS 30 kph

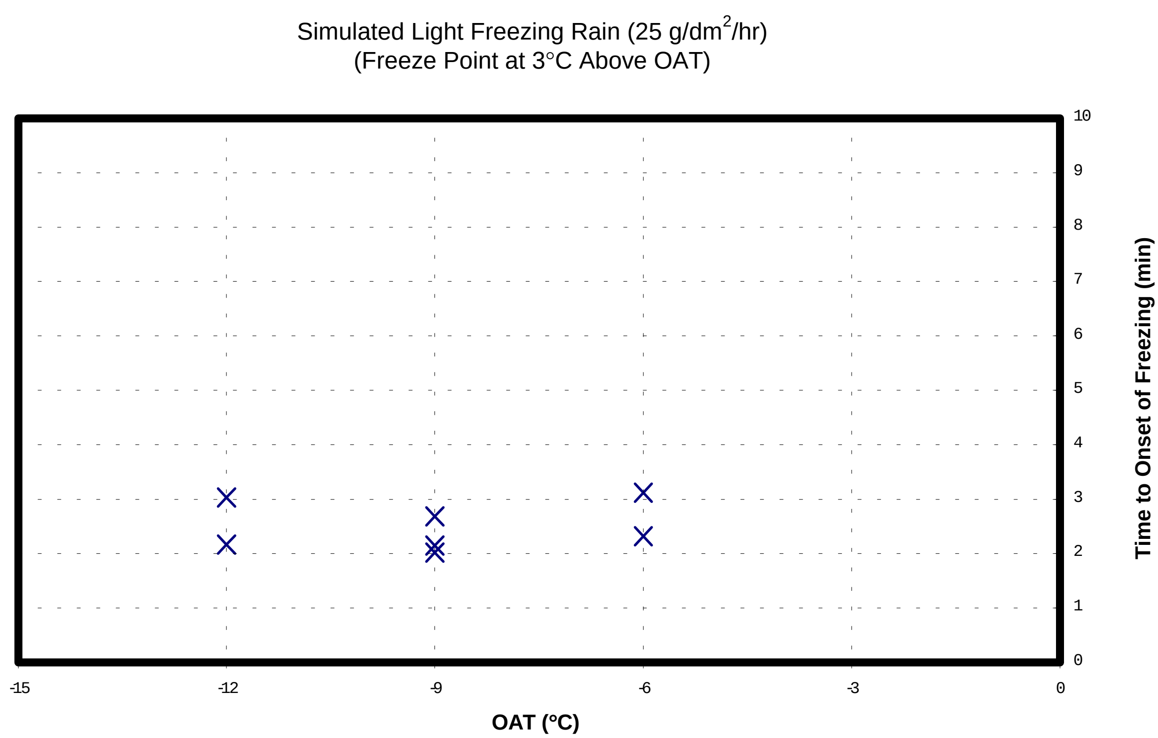



FIGURE 5-5. ELAPSED TIME TO ONSET OF FREEZING – HOT DILUTE TYPE I, CALM WINDS

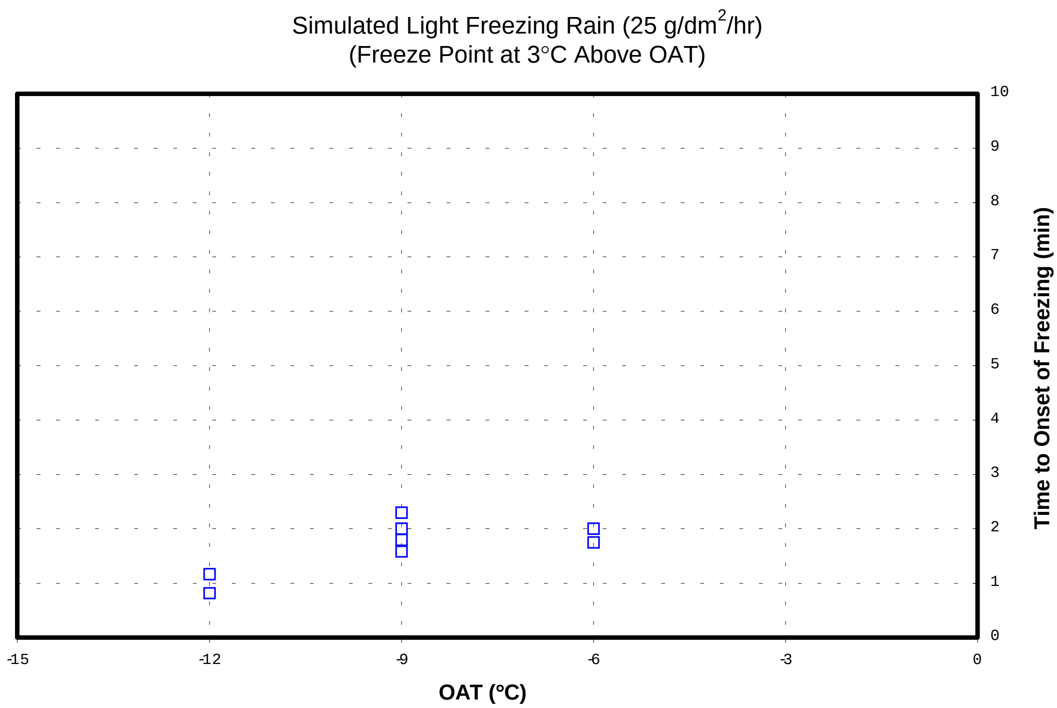



FIGURE 5-6. ELAPSED TIME TO ONSET OF FREEZING – HOT DILUTE TYPE I, WINDS 10 kph

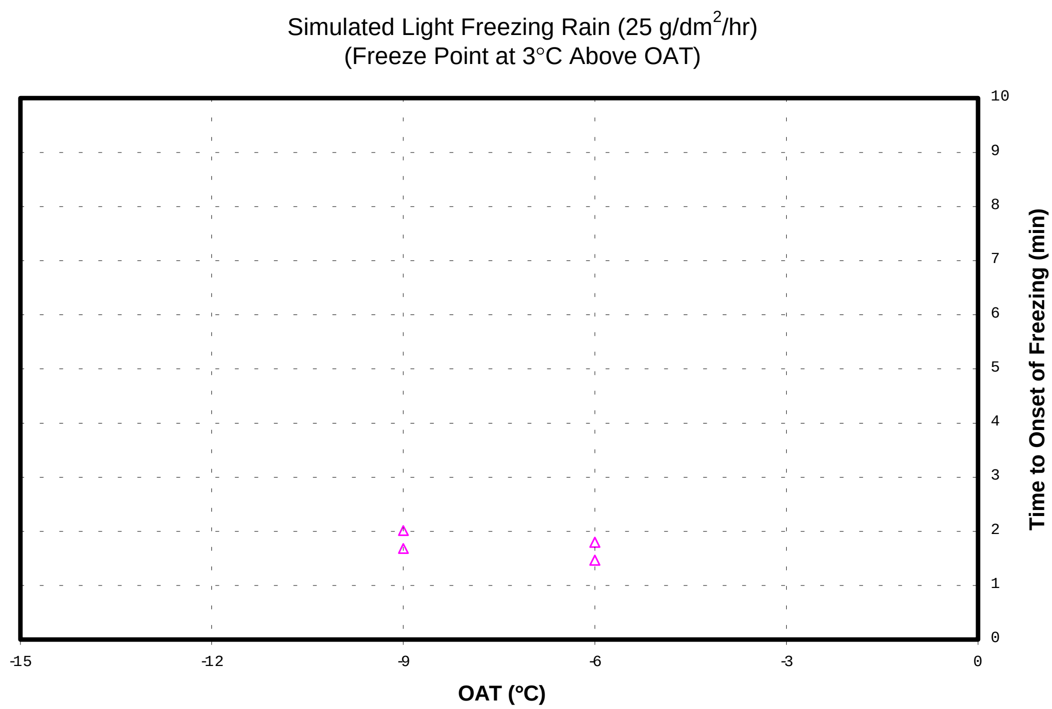



FIGURE 5-7. ELAPSED TIME TO ONSET OF FREEZING – HOT DILUTE TYPE I, WINDS 20 kph

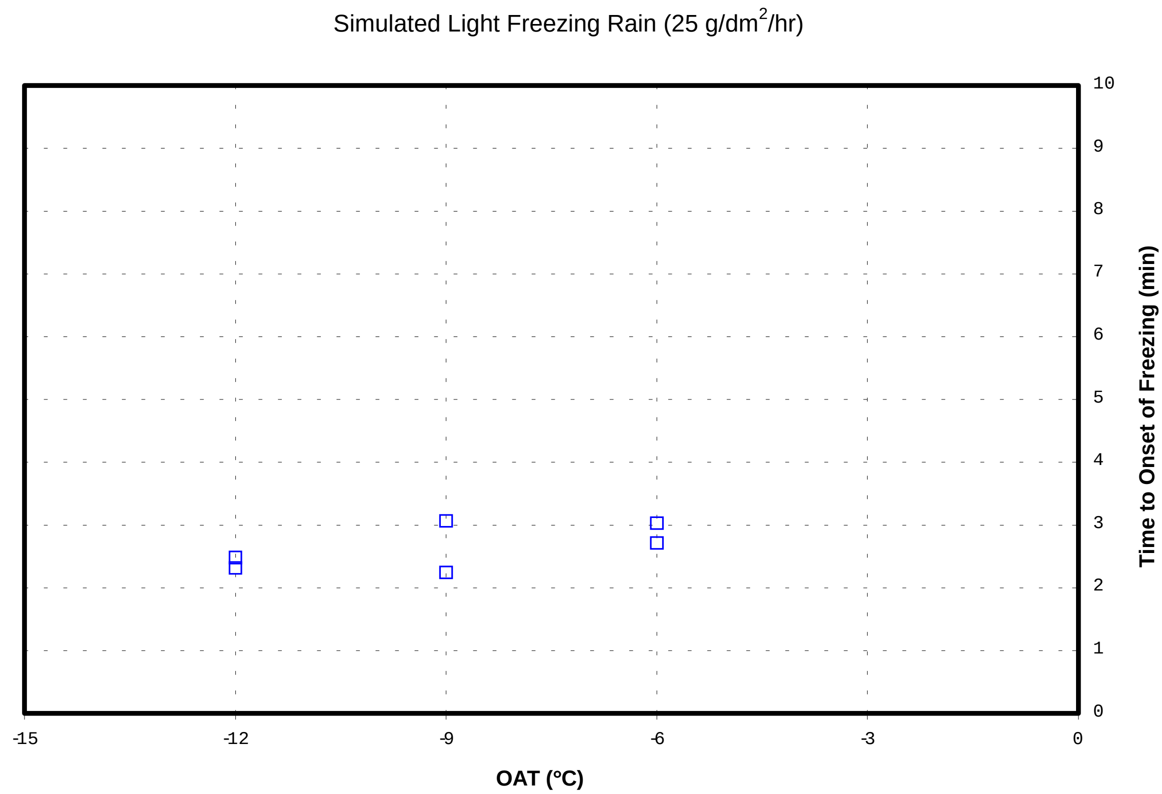



FIGURE 5-8. ELAPSED TIME TO ONSET OF FREEZING – HOT XL54, WINDS 10 kph

5.1.1 Hot Water.

Hot water test results at all wind speeds tested, show a general trend of declining values for elapsed times as a function of colder ambient temperatures. Some peculiarities apparent in the data require discussion.

a. Repeated tests at all values of OAT for calm wind conditions showed a notable scatter in results. At an OAT of -3°C, elapsed time data values varied from 4.7 to 6.3 minutes. This notable range in values did not appear to the same extent in results for tests in wind conditions. The same observation applies to tests conducted using dilute Type I fluids.

b. In calm conditions, the trend line for elapsed time dropped consistently with a reduction of OAT from -3° to -9°C, but then turned upward at -12°C. Such a result appears counter-intuitive. Supplementary tests were conducted at -9°C to confirm results at that temperature. The data from those tests supported previous results. Repeated tests at -12°C in calm conditions also supported previous test data. The additional data points from the repeat tests are included in figure 5.1. This peculiarity is discussed in section 5.1.5.

   The upturn in trend line at -12°C is not apparent in results for tests conducted in wind conditions.

c. The data values for elapsed time at all ambient temperatures were shorter than those observed in previous tests involving hot water. In figure 5-9, results from the 1997-98 First-Step Fluid trials (reported in figure 2-4) are compared to current test results. Test procedures for the two tests were different in that the first-step trials involved application of a standard fluid quantity (500 ml) by pouring on a clean test surface, whereas, in the current trials, fluid was sprayed onto an iced surface in quantities required to clean the surface with a continuing precipitation of simulated light freezing rain. The effect of these procedural differences is explored in later discussions.

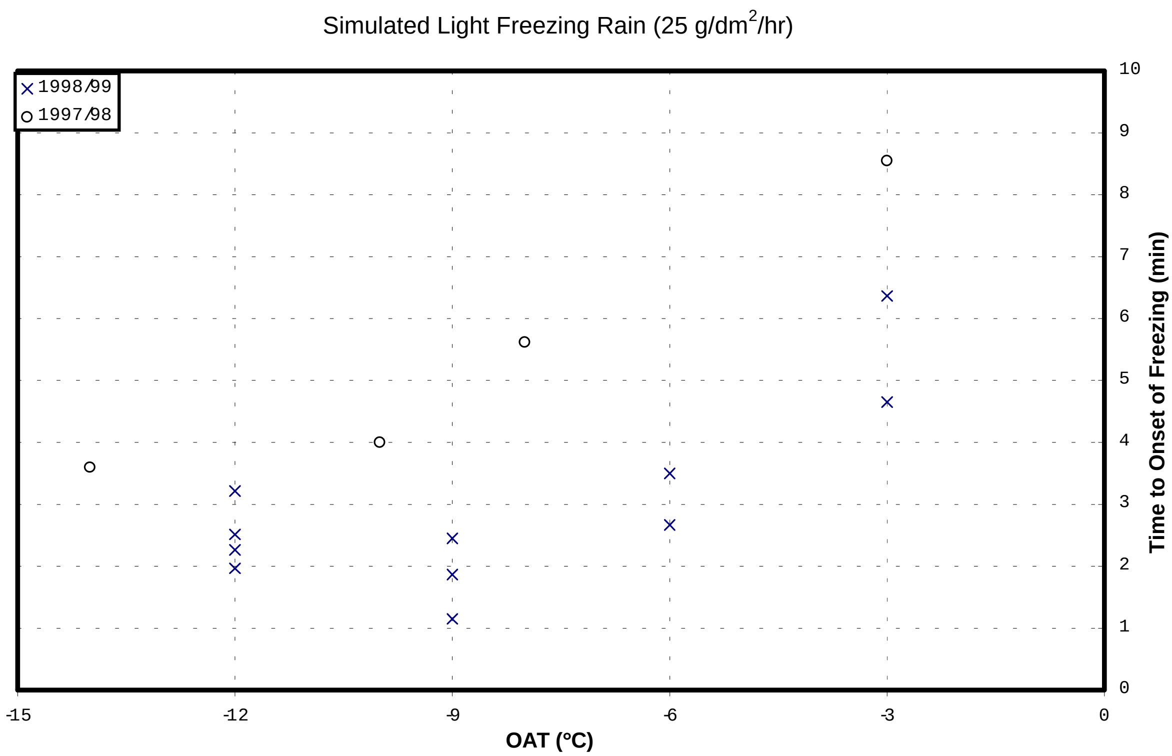



FIGURE 5-9. COMPARISON OF ELAPSED TIMES RESULTS OF 1997-98 FIRST-STEP FLUID TRIALS USING HOT WATER – CALM WINDS

The elapsed times to initial freezing from the current study are also considerably shorter than the results of the field trials on operational aircraft conducted in March-April 1995. The 1995 trials involved spray application on the aircraft by operators experienced in hot water deicing. However, these 1995 tests were conducted in dry conditions. A review of the test record for those trials revealed that the operators sprayed varying amounts, ranging between 20 and 40 gal. (Br) (90 to 180 L) per DC-9 wing. This is equivalent to 300 to 600 ml per test plate area, for an average of 450 ml. This indicates that the test quantities in this series of trials were somewhat conservative, which would contribute to shorter elapsed times prior to freezing.

d. Elapsed times to the onset of freezing in calm winds were approximately 3 minutes and greater at ambient test temperatures of -3° and -6°C (figure 5-1).

With winds of 10 kph and at an OAT of -6°C, elapsed time dropped to between 2 and 3 minutes (figure 5-2). The elapsed time at the OAT of -3°C was 3 minutes and above.

At a wind speed of 20 kph, the only OAT condition producing an elapsed time of 3 minutes was at -3°C (figure 5-3). The single test reported for wind speeds of 30 kph (figure 5-4) gave a similar result of 3 minutes.

Table 5-1 lists elapsed times in minutes for various OAT/wind speed combinations.

TABLE 5-1. ELAPSED TIMES TO ONSET OF FREEZING FOR HOT WATER

| Wind Speed | OAT | | | |
|---|---|---|---|---|
| | -12°C | -9°C | -6°C | -3°C |
| Calm | 2 and over | 1 and over | 2.5 and over | 3 and over |
| 10 kph | 1 and over | 0.5 and over | 2 and over | 3 and over |
| 20 kph | | 0.5 and over | 1.5 and over | 3 and over |
| 30 kph | | | | 3 and over |

5.1.2 Dilute Type I Fluid.

Tests conducted with Type I fluid at the currently approved fluid freeze point limit for first-step fluid deicing (3°C above OAT) produced results very similar to hot water. This fluid was tested at only three OAT conditions, the fluid freeze point at an OAT of -3°C being equivalent to water.

In calm conditions (figure 5-5), values for elapsed times to the onset of freezing were in the range of 2 to 3 minutes for all ambient temperatures tested. As mentioned, in calm conditions at -12°C the resulting data did not continue the expected downward trend.

At a wind condition of 10 kph (figure 5-6), the elapsed times were reduced to 2 minutes or less for all OAT values tested.

At a wind condition of 20 kph (figure 5-7), the elapsed times were reduced to less than 2 minutes for all values of OAT tested.

Table 5-2 lists elapsed times for various OAT/wind speed combinations.

TABLE 5-2. ELAPSED TIME TO ONSET OF FREEZING FOR DILUTE TYPE I FLUID

| Wind Speed | OAT | | | |
|---|---|---|---|---|
| | -12°C | -9°C | -6°C | -3°C |
| Calm | 2 and over | 1.5 and over | 2.5 and over | |
| 10 kph | 0.5 and over | 1.5 and over | 1.5 and over | |
| 20 kph | | 1.5 and over | 1.5 and over | |
| 30 kph | | | | |

5.1.3 Type I Fluid Neat (XL54).

A limited number of tests were conducted with this fluid for comparison purposes, and only at wind speeds of 10 kph (figure 5-8). At an OAT of -6°C an elapsed time of 2.5 to 3 minutes resulted (table 5-3). At colder ambient temperatures, elapsed time reduced slightly to between 2 and 3 minutes.

TABLE 5-3. ELAPSED TIME TO ONSET OF FREEZING FOR TYPE I FLUID NEAT

| Wind Speed | OAT | | | |
|---|---|---|---|---|
| | -12°C | -9°C | -6°C | -3°C |
| Calm | | | | |
| 10 kph | 2 and over | 2 and over | 2.5 and over | |
| 20 kph | | | | |
| 30 kph | | | | |

5.1.4 Comparison of Fluid Types.

Figure 5-10 provides a comparison of results produced with wind speeds of 10 kph by water, dilute Type I, and neat Type I fluid.

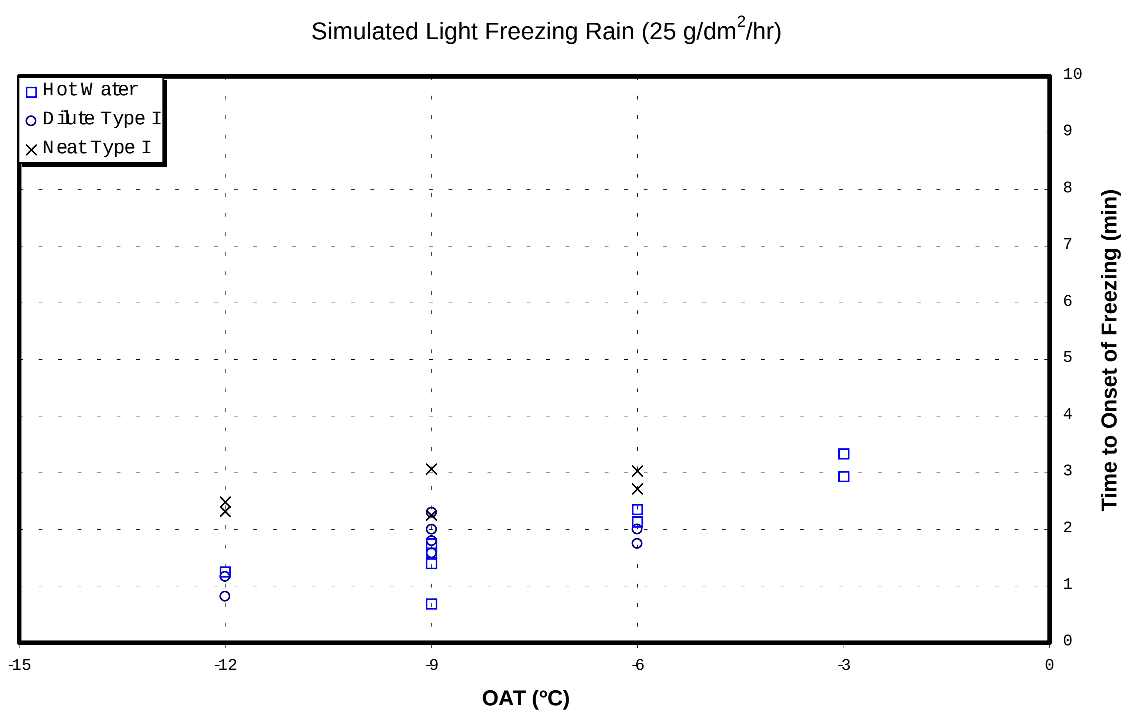



FIGURE 5-10. COMPARISON OF FLUID TYPE – ELAPSED TIME TO ONSET OF FREEZING, WINDS 10 kph

This chart demonstrates how little difference there is in the performance of the three fluids in conditions of light freezing rain. As would be expected, the neat Type I fluid performed better than either water or diluted Type I, but only marginally so at any tested OAT. Water generally performed as well or better than dilute Type I fluid. The slight improvement that full strength Type I fluid offered over water and dilute Type I fluid is explained by the rapid dilution of the freeze point depressant fluids when exposed to the test precipitation rate (light freezing rain). This feature was discussed in section 2.2 as part of a review of previous studies on first-step fluid freeze point buffer requirements.

Charts in which time profiles of surface temperatures and fluid freeze points are plotted, for various OATs, provide a further perspective on test results and are discussed in the following sections.

5.1.5 Effect of OAT.

Figures 5-11, 5-12, and 5-13 illustrate the effect of OAT on the rate of cooling of the test surface. The plots of the test surface temperatures can be compared to the freeze point of the test fluid, thereby allowing an estimation of the time to the onset of freezing at the point of intersection of the two lines. It should be noted that this is purely an estimate as only a single temperature probe was installed on each test plate, and first freezing usually occurred on some edge of the plate. These locations are significantly remote, relative to the locations of the temperature sensors.

Figure 5-11 illustrates the effect of a hot water spray in calm wind and four OAT test conditions. The plate surface temperatures rise instantaneously at the time of fluid application. The surface temperature eventually cools down to ambient. The slope of each of the temperature profiles during the cooling period is an indicator of the rate of cooling. The slope increased with a drop in OAT values. The profile at OAT of -3°C has the shallowest slope and the profile at OAT of -12°C has the steepest. The same observation can be made on the other two figures. The intersection of the surface temperature profiles with the fluid freeze point (0°C) is in all cases significantly later than onset of freezing reported in the chart legend.

Further examination of figure 5-11 provides additional explanation for the upturn in elapsed time values as the OAT moved from -9° to -12°C (noted in the previous sections). In this figure the temperature profile of the -12°C curve peaked at a value higher than the other curves. When the curves are compared to the fluid amounts reported in the legend, it can be seen that the quantity of fluid applied has a direct bearing on peak temperature value. Recall that the quantity of fluid was determined by the amount required to clean the plate surface in each test. It appears that more fluid was required to clean the surface in the colder temperature. The same observation holds for figure 5-12. When profiles for -9° and -12°C are compared, it can be seen that the additional heat transferred to the surface in the -12°C case was more than compensated for by its steeper cooling profile, and resulted in a retarded intersection with the fluid freeze point (0°C). Why more fluid was required at the colder temperature and whether this phenomenon is representative of operations in the field, is open to conjecture.

Figure 5-13 provides a similar display for a Type I fluid. In this chart, the fluid freeze point progressively rises from its initial value to 0°C. The fluids with freeze points of -6° and -9ºC both show an initial enhancement where the freeze point improves (drops) due to evaporation of water from the thin film on the heated surface. This corresponds to the results of the deicing only study [3], except in this case the precipitation quickly overcomes the initial enrichment.

**Simulated Light Freezing Rain (25 g/dm$^2$/hr)**
**ID# 97, 65, 59, & 2**

| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 97 | Water | 0 | -3 | 281 | 0 | 60 | 4.7 | 1.0 | Aluminum |
| 65 | Water | 0 | -6 | 230 | 0 | 60 | 2.7 | 1.0 | Aluminum |
| 59 | Water | 0 | -9 | 204 | 0 | 60 | 1.4 | 1.0 | Aluminum |
| 2 | Water | 0 | -12 | 306 | 0 | 60 | 2.0 | 1.0 | Aluminum |

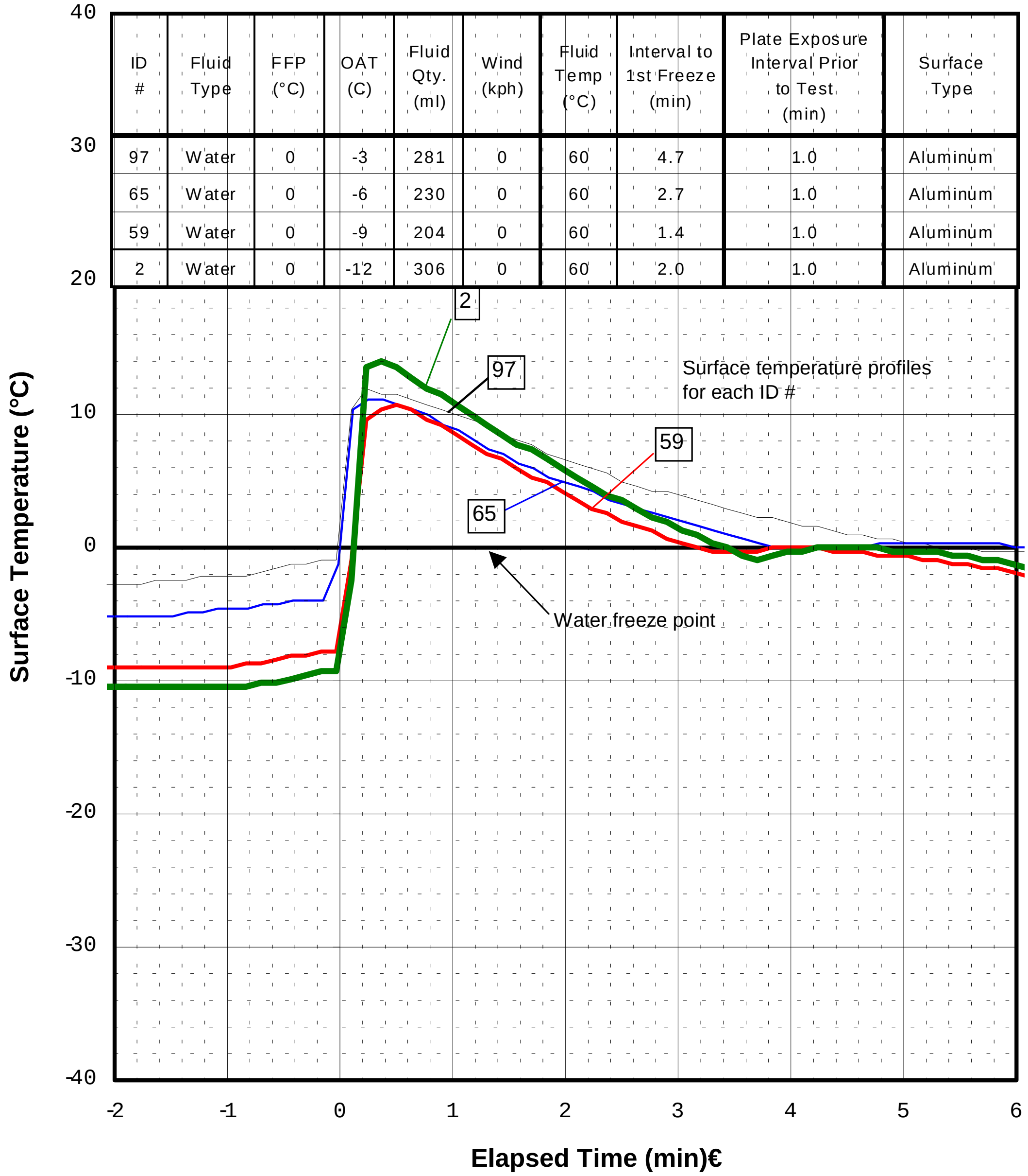
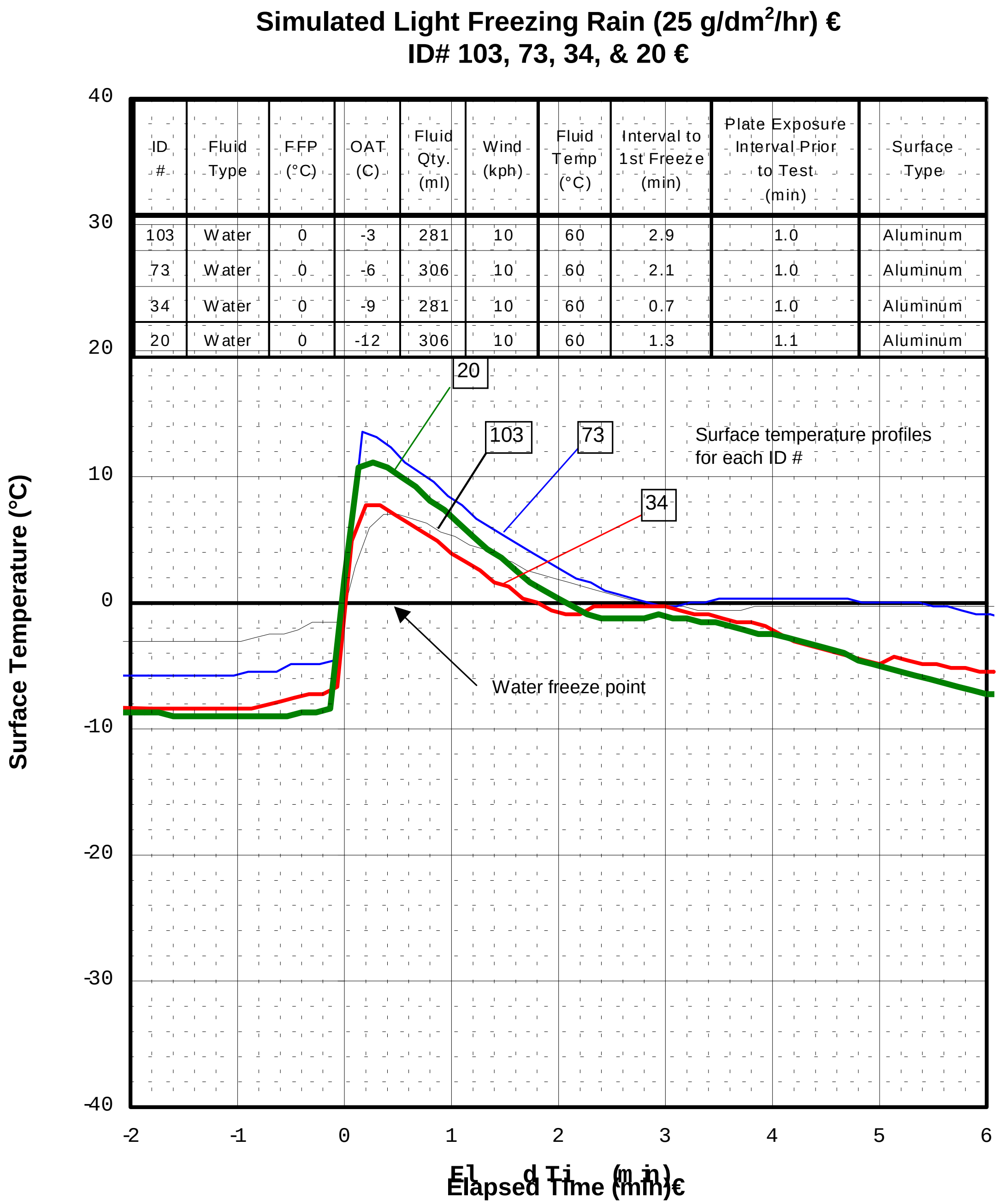
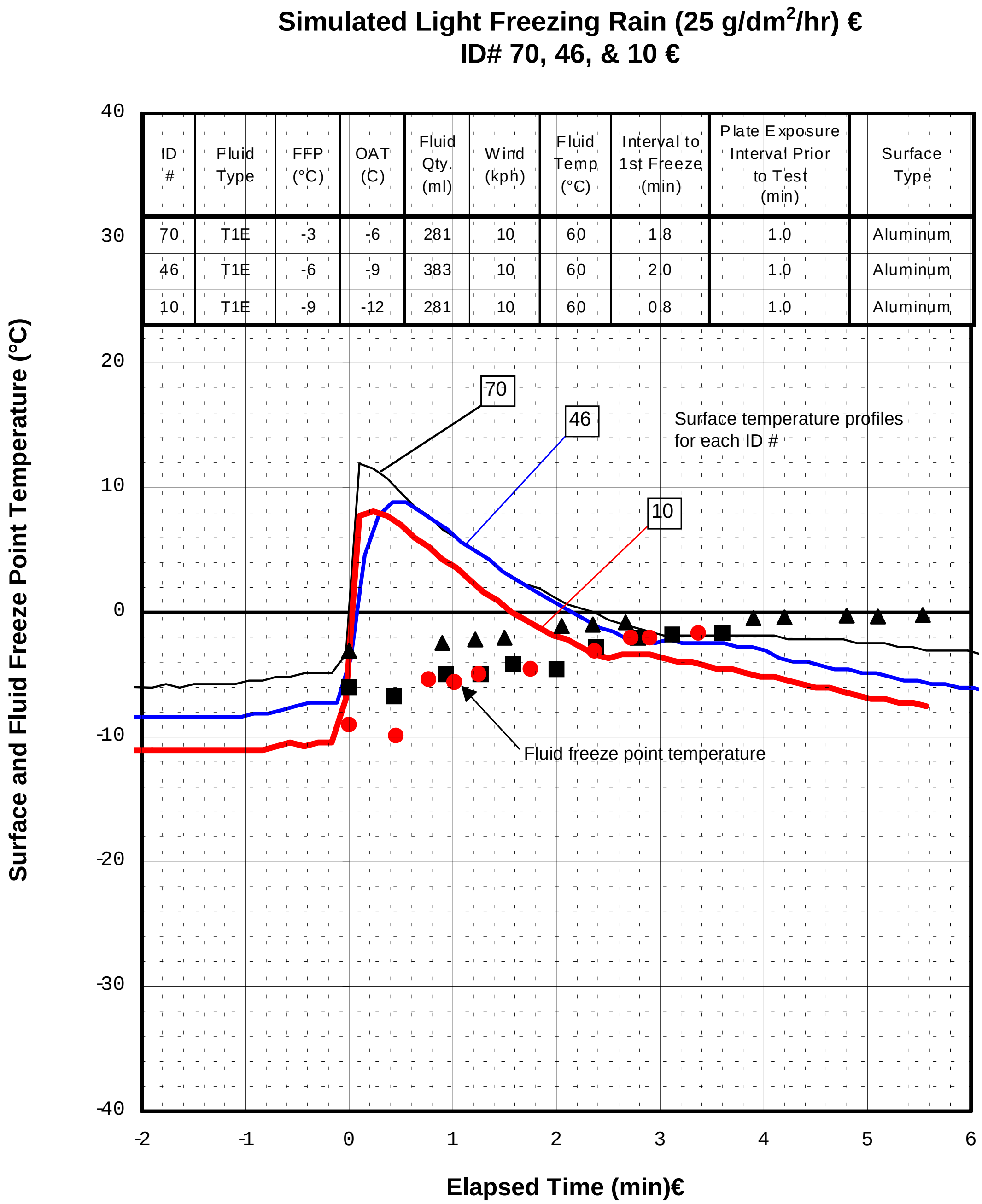



FIGURE 5-11. EFFECT OF OAT, WIND CALM, HOT WATER




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 103 | Water | 0 | -3 | 281 | 10 | 60 | 2.9 | 1.0 | Aluminum |
| 73 | Water | 0 | -6 | 306 | 10 | 60 | 2.1 | 1.0 | Aluminum |
| 34 | Water | 0 | -9 | 281 | 10 | 60 | 0.7 | 1.0 | Aluminum |
| 20 | Water | 0 | -12 | 306 | 10 | 60 | 1.3 | 1.1 | Aluminum |

FIGURE 5-12. EFFECT OF OAT, WIND = 10 kph, HOT WATER

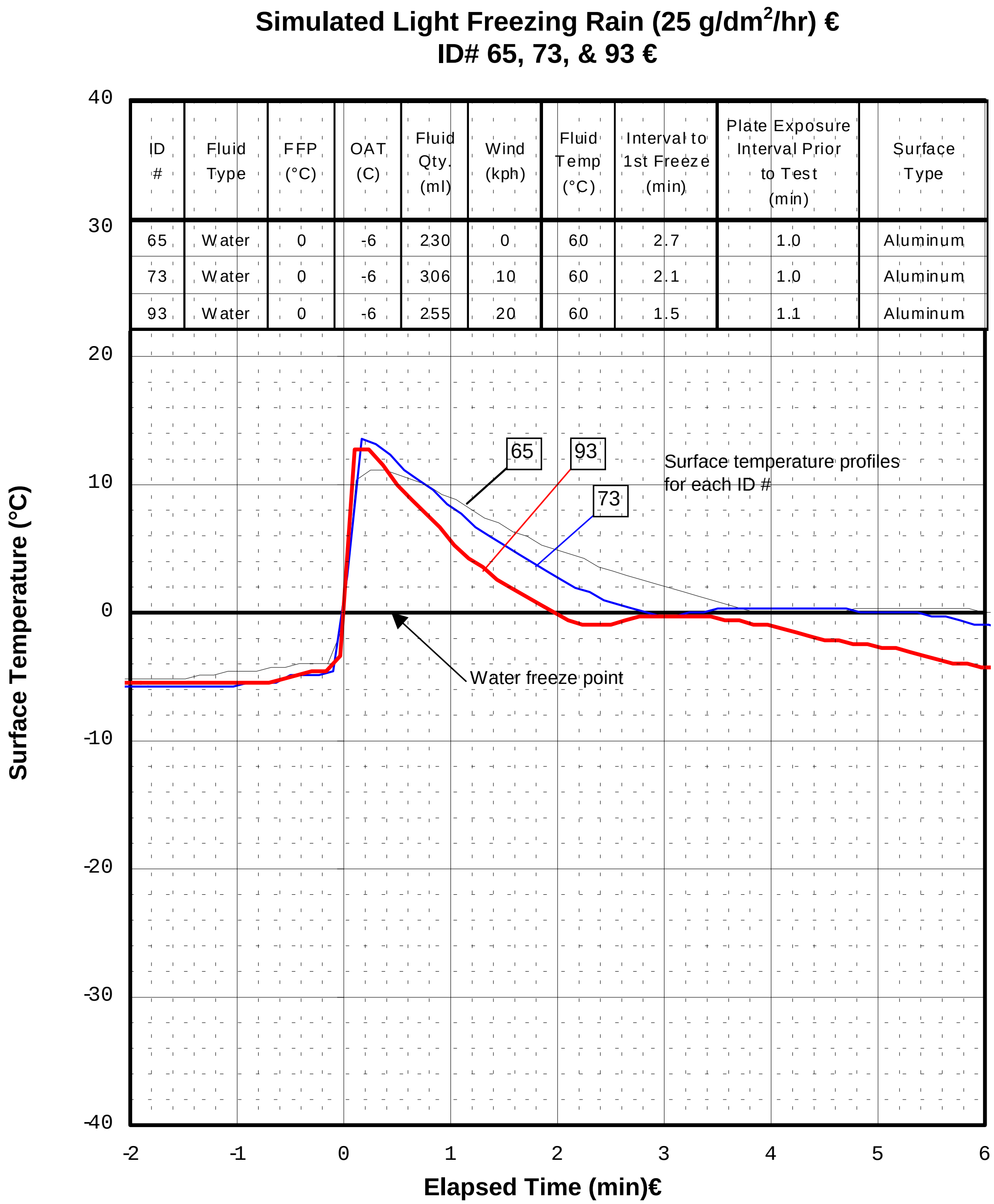



| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 70 | T1E | -3 | -6 | 281 | 10 | 60 | 1.8 | 1.0 | Aluminum |
| 46 | T1E | -6 | -9 | 383 | 10 | 60 | 2.0 | 1.0 | Aluminum |
| 10 | T1E | -9 | -12 | 281 | 10 | 60 | 0.8 | 1.0 | Aluminum |

FIGURE 5-13. EFFECT OF OAT, WIND = 10 kph, HOT TYPE I

5.1.6 Effect of Wind Speed.

Figures 5-14 and 5-15 illustrate the influence of wind on surface cooling rates, and thereby on time interval to the onset of freezing after the application of hot water. In figure 5-14 the temperature profiles for plates treated with hot water show progressively steeper slopes and more rapid cooling in going from calm wind conditions to winds of 20 kph. In wind conditions, this translates directly to an earlier intersection with the fluid freeze point curve and an earlier onset of freezing.




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 65 | Water | 0 | -6 | 230 | 0 | 60 | 2.7 | 1.0 | Aluminum |
| 73 | Water | 0 | -6 | 306 | 10 | 60 | 2.1 | 1.0 | Aluminum |
| 93 | Water | 0 | -6 | 255 | 20 | 60 | 1.5 | 1.1 | Aluminum |

FIGURE 5-14. EFFECT OF WIND AT OAT = -6ºC, HOT WATER

Figure 5-15 presents a similar view for an application of dilute Type I fluid. This figure illustrates the effect of wind speed at a constant OAT of -6°C. Although the surface temperatures during the cooling periods clearly show the effect of wind speed, it is interesting that the time to onset of first freezing was the same for winds of 10 and 20 kph.

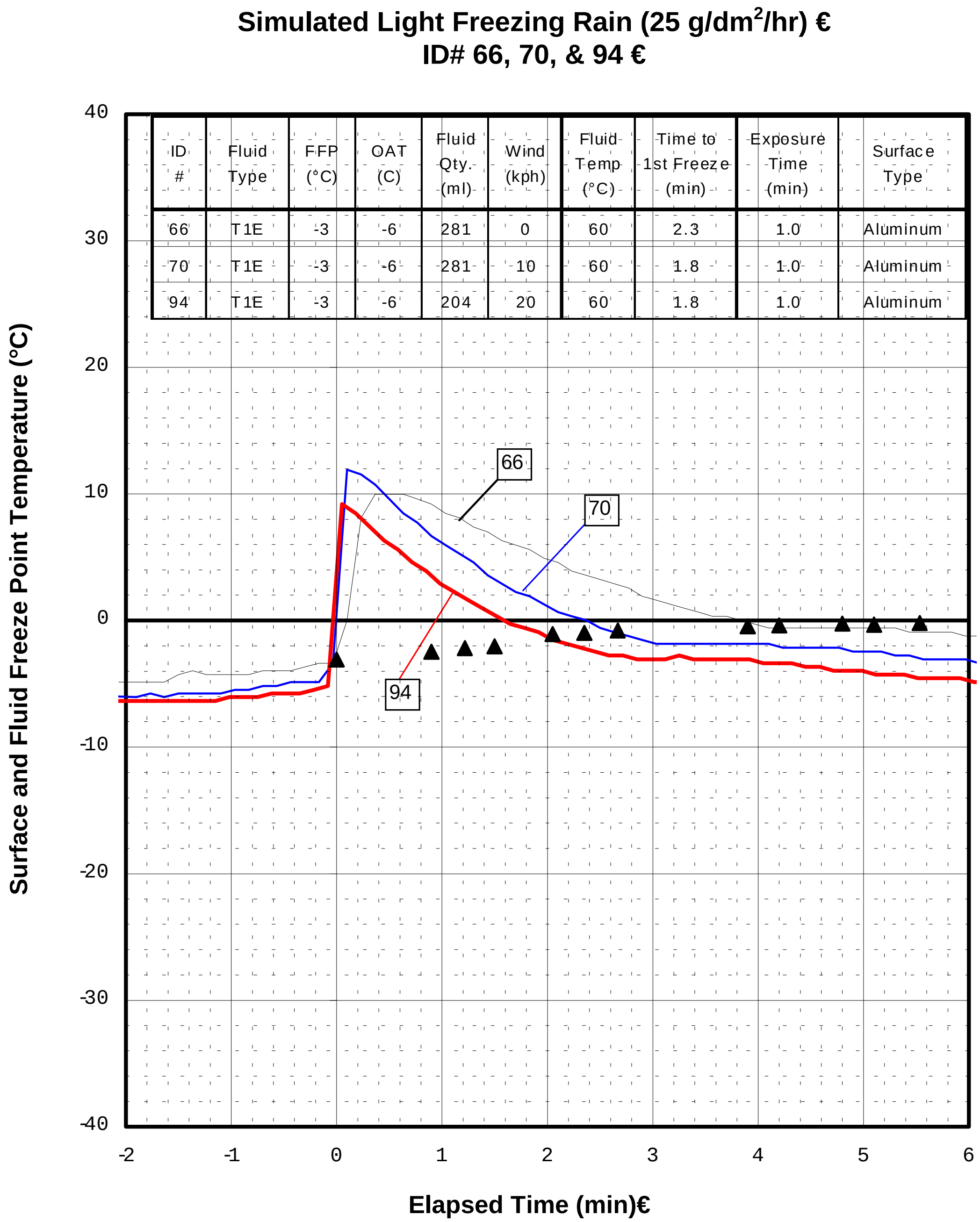
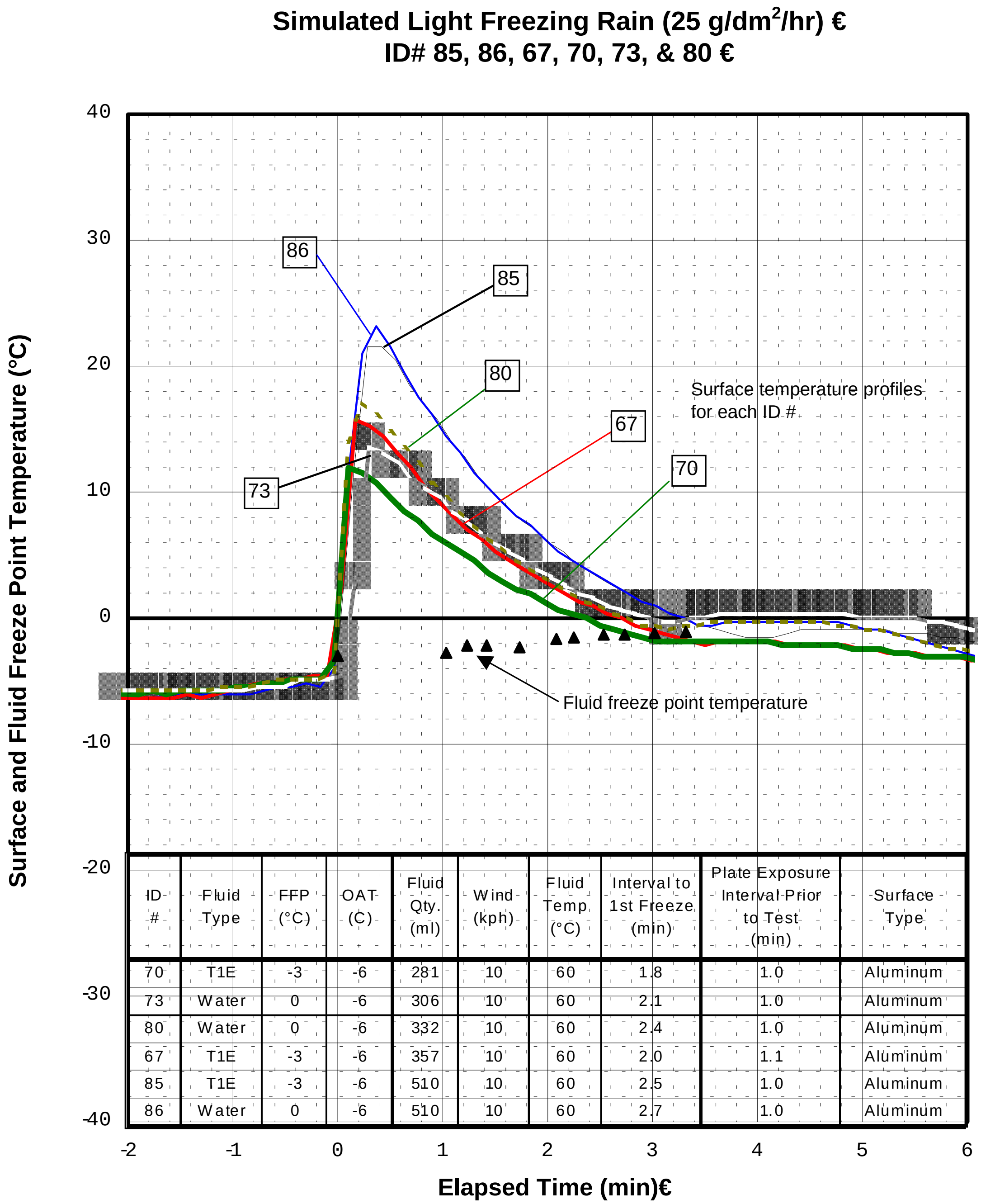



FIGURE 5-15. EFFECT OF WIND AT OAT = -6ºC, HOT TYPE I

5.1.7 Effect of Fluid Type.

Figure 5-16 provides a further perspective on the comparison of the performance of water versus Type I fluid (mixed to the approved freeze point). The identical profiles for tests 85 (Type I) and 86 (water) reflect completely common test conditions. The other tests shown have some differences in fluid quantities and this is reflected both in the peak values of the temperature profiles and in elapsed time to the initiation of freezing. In these tests, water performed as well or better than Type I fluid.

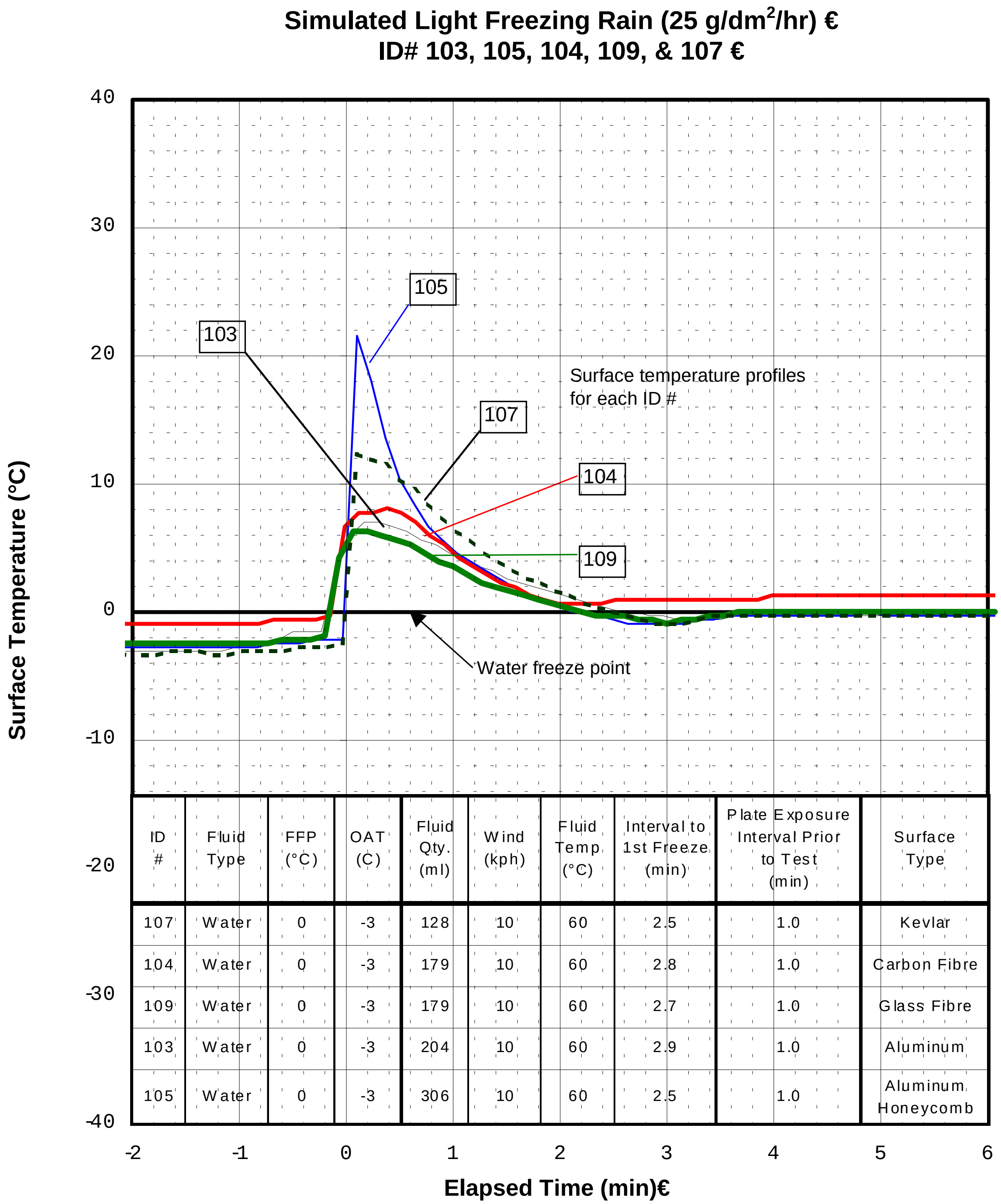



| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 70 | T1E | -3 | -6 | 281 | 10 | 60 | 1.8 | 1.0 | Aluminum |
| 73 | Water | 0 | -6 | 306 | 10 | 60 | 2.1 | 1.0 | Aluminum |
| 80 | Water | 0 | -6 | 332 | 10 | 60 | 2.4 | 1.0 | Aluminum |
| 67 | T1E | -3 | -6 | 357 | 10 | 60 | 2.0 | 1.1 | Aluminum |
| 85 | T1E | -3 | -6 | 510 | 10 | 60 | 2.5 | 1.0 | Aluminum |
| 86 | Water | 0 | -6 | 510 | 10 | 60 | 2.7 | 1.0 | Aluminum |

FIGURE 5-16. EXAMINATION OF FLUID QUANTITY AND TYPE, WIND = 10 kph, OAT = -6ºC

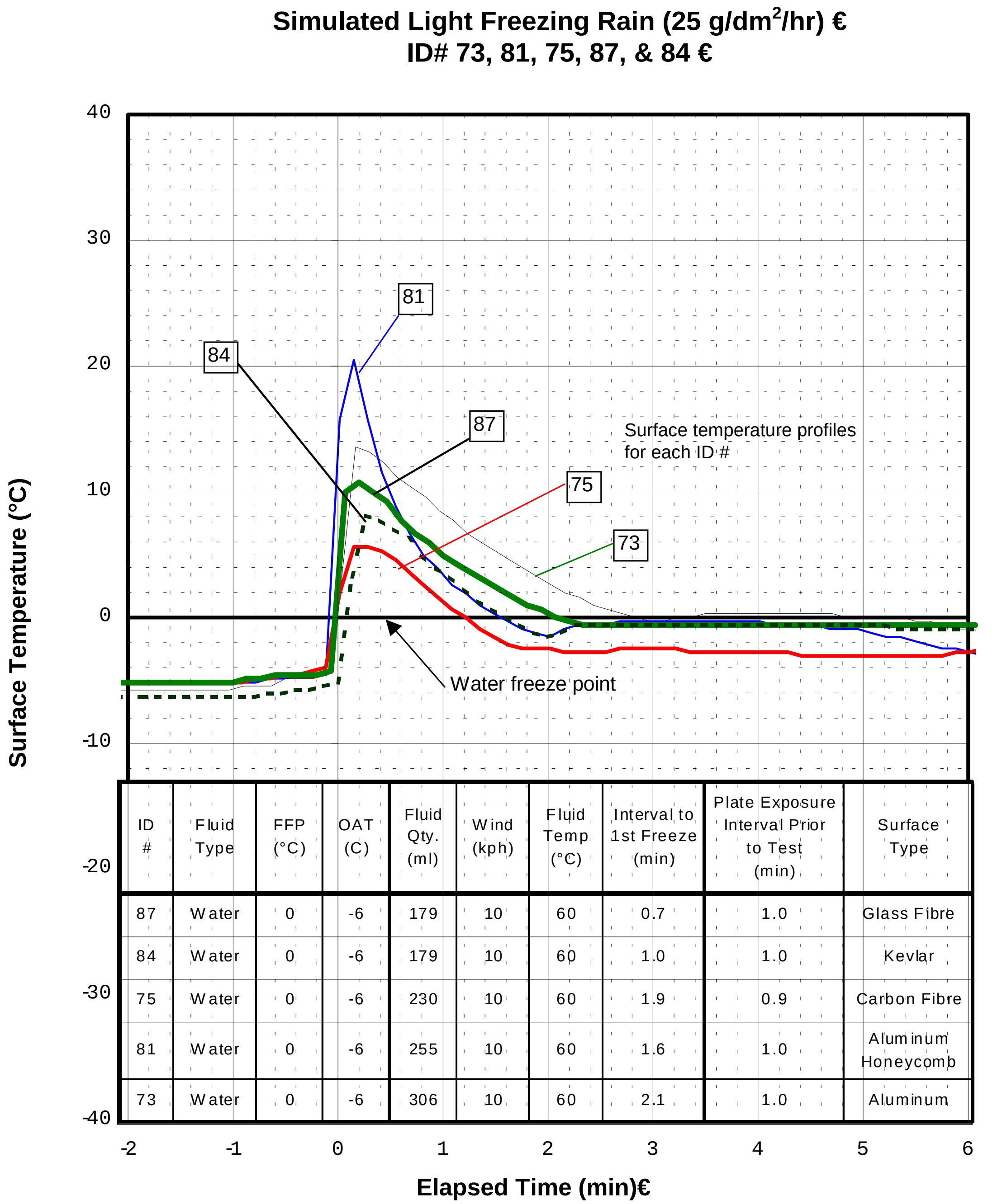
5.1.8 Effect of Composite Surfaces.

Figures 5-17, 5-18, and 5-19 present the test results of fluid application on surfaces of various composition. In these tests, the various surfaces were all contaminated to the same level, and fluid was sprayed until a clean surface was achieved.



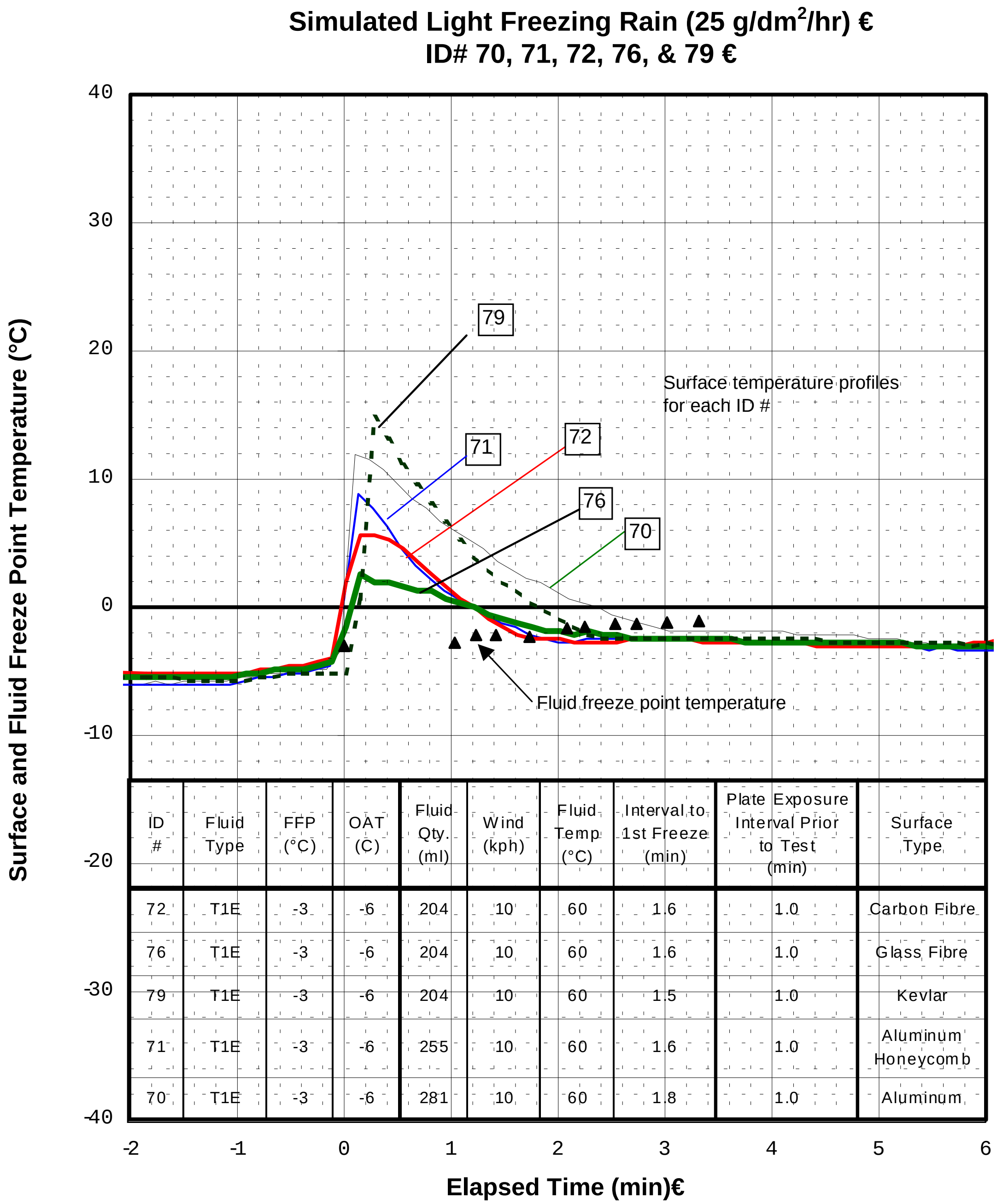

| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp. (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 107 | Water | 0 | -3 | 128 | 10 | 60 | 2.5 | 1.0 | Kevlar |
| 104 | Water | 0 | -3 | 179 | 10 | 60 | 2.8 | 1.0 | Carbon Fibre |
| 109 | Water | 0 | -3 | 179 | 10 | 60 | 2.7 | 1.0 | Glass Fibre |
| 103 | Water | 0 | -3 | 204 | 10 | 60 | 2.9 | 1.0 | Aluminum |
| 105 | Water | 0 | -3 | 306 | 10 | 60 | 2.5 | 1.0 | Aluminum Honeycomb |

FIGURE 5-17. EFFECT OF PLATE COMPOSITION, OAT = -3ºC, HOT WATER




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 87 | Water | 0 | -6 | 179 | 10 | 60 | 0.7 | 1.0 | Glass Fibre |
| 84 | Water | 0 | -6 | 179 | 10 | 60 | 1.0 | 1.0 | Kevlar |
| 75 | Water | 0 | -6 | 230 | 10 | 60 | 1.9 | 0.9 | Carbon Fibre |
| 81 | Water | 0 | -6 | 255 | 10 | 60 | 1.6 | 1.0 | Aluminum Honeycomb |
| 73 | Water | 0 | -6 | 306 | 10 | 60 | 2.1 | 1.0 | Aluminum |

FIGURE 5-18. EFFECT OF PLATE COMPOSITION, OAT = -6ºC, HOT WATER




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 72 | T1E | -3 | -6 | 204 | 10 | 60 | 1.6 | 1.0 | Carbon Fibre |
| 76 | T1E | -3 | -6 | 204 | 10 | 60 | 1.6 | 1.0 | Glass Fibre |
| 79 | T1E | -3 | -6 | 204 | 10 | 60 | 1.5 | 1.0 | Kevlar |
| 71 | T1E | -3 | -6 | 255 | 10 | 60 | 1.6 | 1.0 | Aluminum Honeycomb |
| 70 | T1E | -3 | -6 | 281 | 10 | 60 | 1.8 | 1.0 | Aluminum |

FIGURE 5-19. EFFECT OF PLATE COMPOSITION, OAT = -6ºC, HOT TYPE I

In each of the three charts, the surface temperatures follow very different profiles, primarily with respect to the peak temperature recorded. Referring to figure 5-17, the different peak values do not seem to have a direct bearing on the elapsed times. When the fluid quantities shown in the legend box are examined, it is noted that quantities for aluminum and aluminum on honeycomb core are higher than for the other composite surfaces. This feature is common to each of the three conditions charted.

To explore this further, table 5-4 was devised to examine the relative values of fluid quantities and elapsed times for the different surfaces.

TABLE 5-4. STUDY OF COMPOSITE SURFACES, WINDS 10 kph, FREEZING RAIN (25 g/dm$^2$/hr)

Hot Water, OAT -3°C

| Surface Type | Fluid Quantity (ml) | Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio) | Elapsed Time to Onset of Freezing (min) | Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio) |
|---|---|---|---|---|
| Aluminum | 204 | 1.6 | 2.9 | 1.2 |
| Aluminum on Honeycomb | 306 | 2.4 | 2.5 | 1.0 |
| Carbon Fibre | 179 | 1.4 | 2.8 | 1.1 |
| Glass Fibre | 179 | 1.4 | 2.7 | 1.1 |
| Kevlar | 128 | 1.0 | 2.5 | 1.0 |

Hot Water, OAT -6°C

| Surface Type | Fluid Quantity (ml) | Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio) | Elapsed Time to Onset of Freezing (min) | Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio) |
|---|---|---|---|---|
| Aluminum | 306 | 1.7 | 2.1 | 3.0 |
| Aluminum on Honeycomb | 255 | 1.4 | 1.6 | 2.3 |
| Carbon Fibre | 230 | 1.3 | 1.9 | 2.7 |
| Glass Fibre | 179 | 1.0 | 0.7 | 1.0 |
| Kevlar | 179 | 1.0 | 1.0 | 1.4 |

Hot Dilute Type I, OAT -6°C

| Surface Type | Fluid Quantity (ml) | Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio) | Elapsed Time to Onset of Freezing (min) | Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio) |
|---|---|---|---|---|
| Aluminum | 281 | 1.4 | 1.8 | 1.2 |
| Aluminum on Honeycomb | 255 | 1.3 | 1.6 | 1.1 |
| Carbon Fibre | 204 | 1.0 | 1.6 | 1.1 |
| Glass Fibre | 204 | 1.0 | 1.6 | 1.1 |
| Kevlar | 204 | 1.0 | 1.5 | 1.0 |

The table illustrates the degree to which fluid quantities for the carbon fibre, glass fibre, and Kevlar composite surfaces are lower than for the two types of aluminum surfaces. The elapsed time to freezing generally shows a direct relationship to quantity of applied fluid, except for the aluminum honeycomb case. For aluminum honeycomb, the onset of freezing was within the range for the other materials in this table, however, it did not appear to be commensurate with applied fluid quantity and was shorter than expected. This was most pronounced at an OAT of -3°C and less so at -6°C. The observation on the honeycomb core surface is supported by previous deicing fluid trials on operational aircraft where wing surfaces fabricated of this material were the first to exhibit failure.

The observation that consistently smaller fluid quantities were needed in order to provide a clean surface in the case of the nonaluminum composites is of interest. A possible explanation may lie in the fact that these surfaces were painted, and perhaps the contaminant had a lower level of adhesion than it did on the aluminum surfaces.

Extending the observation to an operational setting is somewhat questionable. Normally the major part of a wing surface is aluminum, with various wing components being fabricated of composite materials, which are painted. In a deicing operation, the operator would tend to apply fluid at the same rate over the entire wing, which is generally performed in a sweeping action encompassing both aluminum and composite surfaces. In such a scenario, the amount of fluid applied would be controlled by the wing surface requiring the greatest amount of fluid, and as a result, the composite surfaces would receive the same rates of application as the aluminum. In other words, the composite surfaces would have to receive a surplus of fluid over and above that amount needed to achieve a clean surface. The effect of the surplus fluid quantity on the period of protection for the composite surfaces is not known. In this study, the effect of various fluid quantities was explored, but associated tests were conducted only on aluminum surfaces. These tests are discussed in later sections.

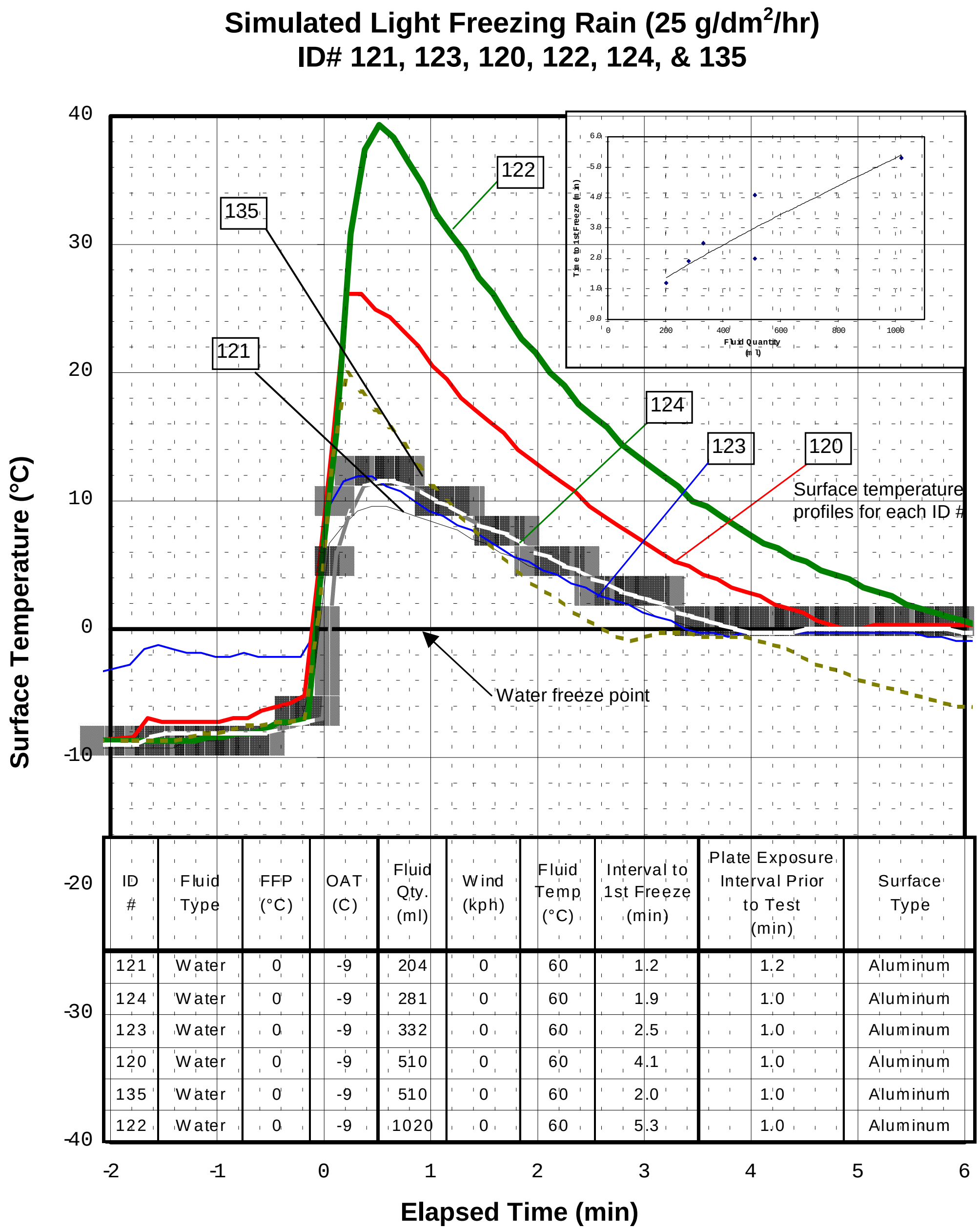
## 5.2 EXAMINATION OF THE INFLUENCE OF TEST PARAMETERS ON RESULTS.

### 5.2.1 Effect of Fluid Quantity.

As discussed in the description of test procedures, the method of fluid application used in these trials was selected in conjunction with a decision to test on contaminated surfaces. The amount of fluid was not prescribed, and the operator was instructed to spray until a clean surface was achieved. This did result in differences in fluid quantities applied. In figures 5-11 and 5-12, for example, the fluid quantities for the eight tests reported ranged from 204 to 306 ml.

As previously noted (section 5.1.5) there was a greater amount of fluid required in the -12°C OAT condition. In general, the quantities of fluid applied were less than the quantities of fluid employed in previous tests when fluids were applied by pouring on clean plates. A fluid quantity of 500 ml was commonly used in these previous tests.

A number of special tests with varying fluid quantities were conducted to examine the effect fluid quantity has on elapsed time to the onset of freezing. Figure 5-20 graphically illustrates the impact fluid quantity has on peak temperature and on the time interval to first freezing in calm wind conditions. The inset charts the time to the onset of freezing versus quantity of fluid

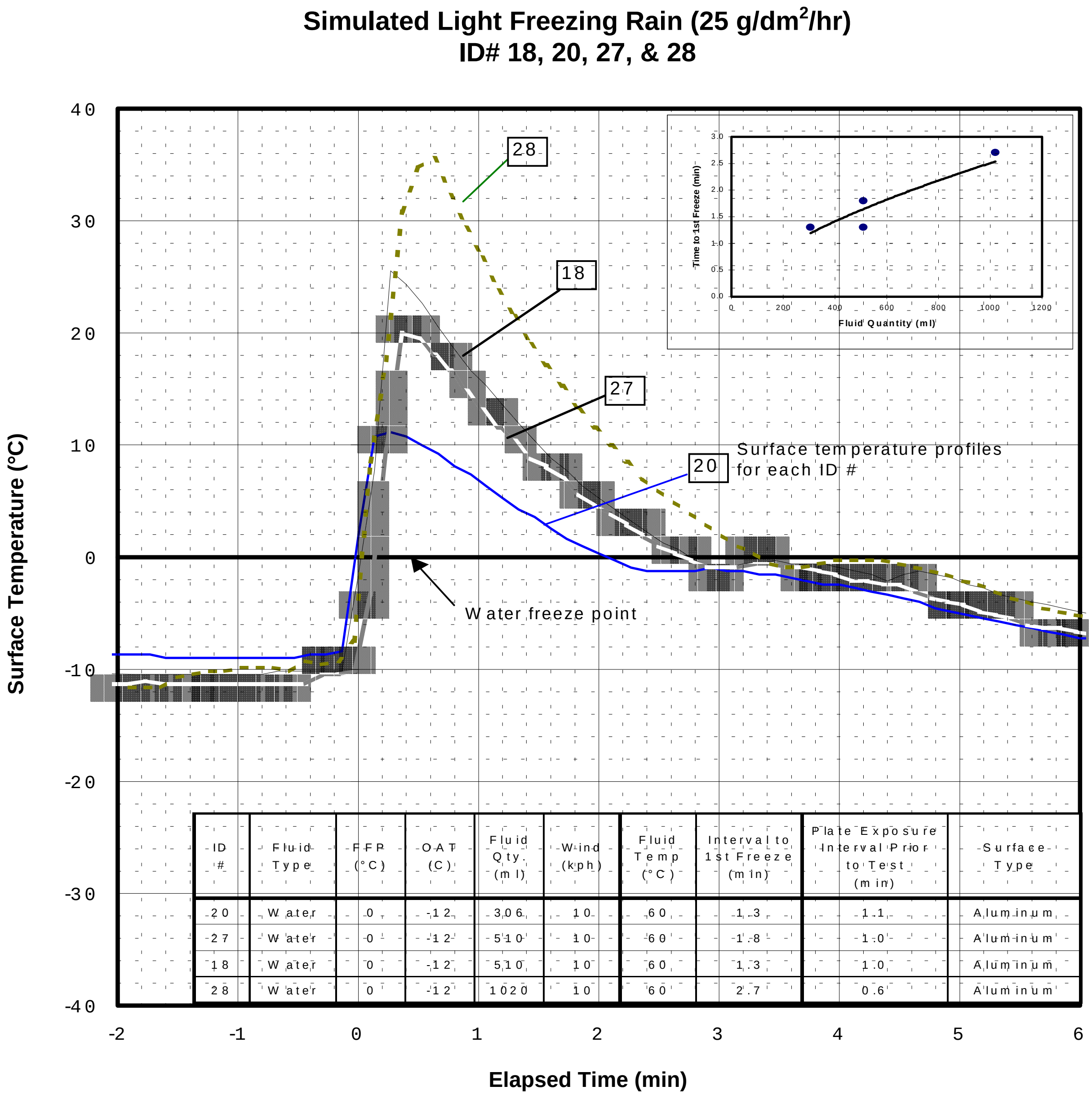



| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 121 | Water | 0 | -9 | 204 | 0 | 60 | 1.2 | 1.2 | Aluminum |
| 124 | Water | 0 | -9 | 281 | 0 | 60 | 1.9 | 1.0 | Aluminum |
| 123 | Water | 0 | -9 | 332 | 0 | 60 | 2.5 | 1.0 | Aluminum |
| 120 | Water | 0 | -9 | 510 | 0 | 60 | 4.1 | 1.0 | Aluminum |
| 135 | Water | 0 | -9 | 510 | 0 | 60 | 2.0 | 1.0 | Aluminum |
| 122 | Water | 0 | -9 | 1020 | 0 | 60 | 5.3 | 1.0 | Aluminum |

FIGURE 5-20. EFFECT OF FLUID QUANTITY, WIND CALM, OAT = -9ºC, HOT WATER

applied. Clearly, the amount of fluid applied in the first step has a direct bearing on the elapsed time before the onset of freezing, or in an operational setting, on the period of safety available to the deicing operator before applying a protective overspray of an anti-icing fluid.

Figure 5-21 (OAT of -12°C and a 10 kph wind condition) further illustrates the effect of fluid quantity. It is interesting to note that the period of protection provided by a water spray of 1020 ml (three times the required quantity) was 2.7 minutes. This is equivalent to the protection times provided by XL54 trials reported in figure 5-10. This quantity of fluid (1020 ml on a standard test plate) is equivalent to 300 L (80 US gal.) on a DC-9 wing.

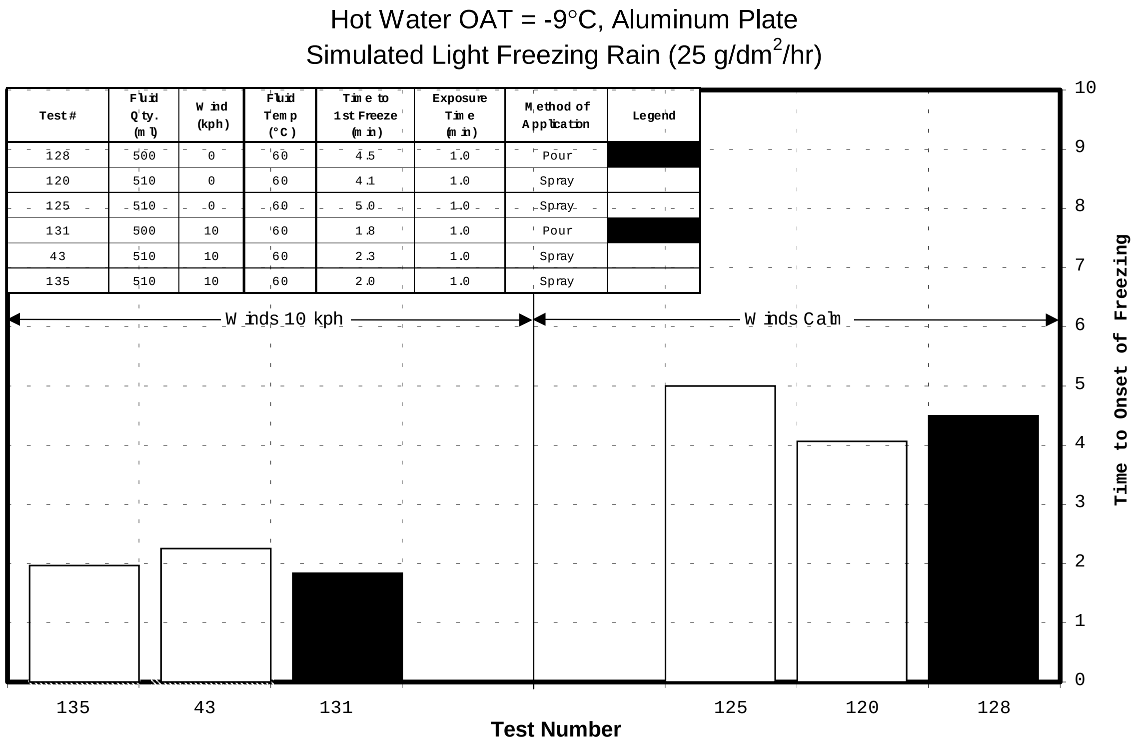



| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 20 | Water | 0 | -12 | 306 | 10 | 60 | 1.3 | 1.1 | Aluminum |
| 27 | Water | 0 | -12 | 510 | 10 | 60 | 1.8 | 1.0 | Aluminum |
| 18 | Water | 0 | -12 | 510 | 10 | 60 | 1.3 | 1.0 | Aluminum |
| 28 | Water | 0 | -12 | 1020 | 10 | 60 | 2.7 | 0.6 | Aluminum |

FIGURE 5-21. EFFECT OF FLUID QUANTITY, WIND = 10 kph, OAT = -12ºC, HOT WATER

5.2.2 Method of Application.

Several special tests were conducted to compare the effect of pouring versus spraying. Figure 5-22 presents the results of tests conducted at an OAT of -9°C, both in calm conditions and with a wind of 10 kph. In these tests, a common quantity of fluid was applied to the plates both by spraying and by pouring with a standard degree of contamination (1 minute exposure to freezing rain at 25 g/dm$^2$/hr). The resulting elapsed times to freezing are not significantly different.




| Test # | Fluid Q'ty. (ml) | Wind (kph) | Fluid Temp (°C) | Time to 1st Freeze (min) | Exposure Time (min) | Method of Application | Legend |
|---|---|---|---|---|---|---|---|
| 128 | 500 | 0 | 60 | 4.5 | 1.0 | Pour | |
| 120 | 510 | 0 | 60 | 4.1 | 1.0 | Spray | |
| 125 | 510 | 0 | 60 | 5.0 | 1.0 | Spray | |
| 131 | 500 | 10 | 60 | 1.8 | 1.0 | Pour | |
| 43 | 510 | 10 | 60 | 2.3 | 1.0 | Spray | |
| 135 | 510 | 10 | 60 | 2.0 | 1.0 | Spray | |

FIGURE 5-22. COMPARISON OF METHOD OF FLUID APPLICATION SPRAYED VS POURED – HOT WATER, OAT = -9°C, ALUMINUM PLATE

Figure 5-23 compares results for pouring 500 ml of hot water on clean and contaminated test surfaces, and for spraying both 510 ml and amounts as required on contaminated surfaces. The comparison of pouring 500 ml on a clean plate (tests 102 and 129), versus spraying a quantity as required on a contaminated plate (tests 97 and 59) is striking. The differences in elapsed time to onset of freezing in this comparison conforms to the variance between current test results and results from previous tests illustrated in figure 5-9. Figure 5-24 provides a further illustration of the difference in results, in wind speeds of 10 kph.

It can be concluded that, given the same quantities of fluid applied, similar results are produced by the two methods of fluid application. The principal difference lies with the amounts applied; the current test procedures require the operator to spray until the surface is clean and resulted in the application of considerably less fluid than the standard 500 ml used in the previous sets of tests.

5.2.3 Degree of Test Surface Contamination.

As part of the test procedure, ice contamination was allowed to form on the test plates and was then removed by spraying as much fluid as necessary to clean the test surface. The degree of contamination was controlled by the length of time that the test plate was exposed to the freezing rain precipitation prior to application of the heated fluid spray. An exposure time of one minute was used as a standard, with multiples of that interval tested in some runs to examine the effect on results.

Simulated Light Freezing Rain (25 g/dm²/hr)

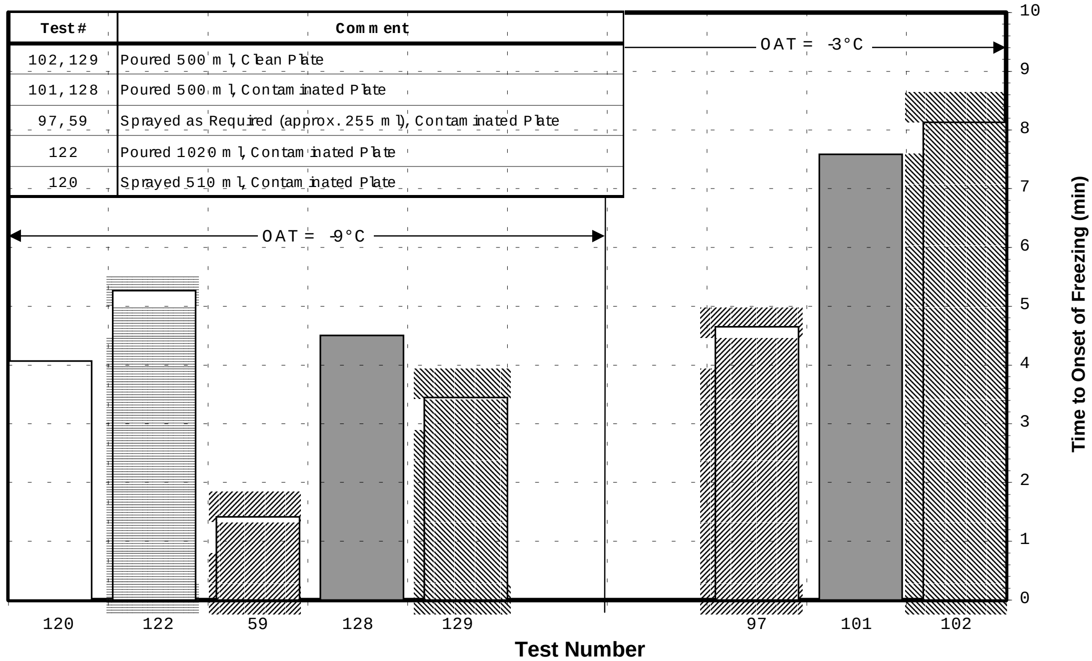



FIGURE 5-23. INFLUENCE OF TYPE OF APPLICATION AND FLUID QUANTITY – HOT WATER, WINDS CALM

Simulated Light Freezing Rain (25 g/dm²/hr)

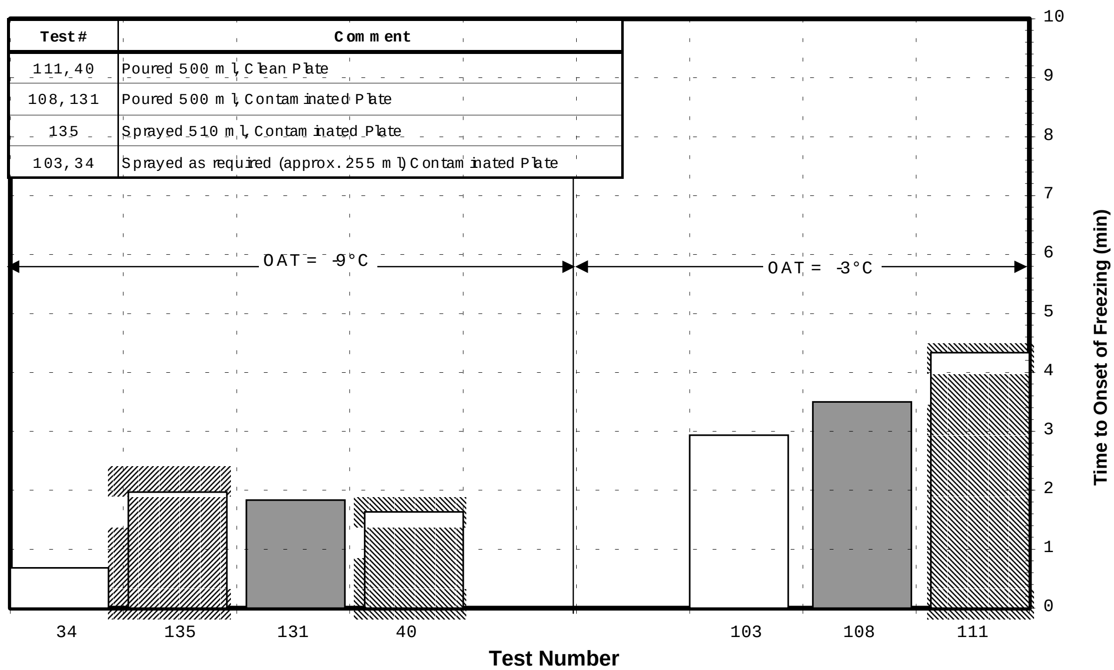



FIGURE 5-24. INFLUENCE OF TYPE OF APPLICATION AND FLUID QUANTITY – HOT WATER, WIND = 10 kph

At the ambient test temperatures, the freezing rain immediately froze upon striking the plate, and very little if any escaped from the surface. This was confirmed by weighing test plates before and after a timed period of exposure, and then using those values to calculate the rate of precipitation. The calculated rate was virtually the same as that measured through the standard procedures for establishing precipitation rates.

Several tests were conducted to examine the effect of varying the degree of contamination. In these tests, precipitation was allowed to accumulate for longer periods prior to spraying. Figures 5-25 and 5-26 present these test results.

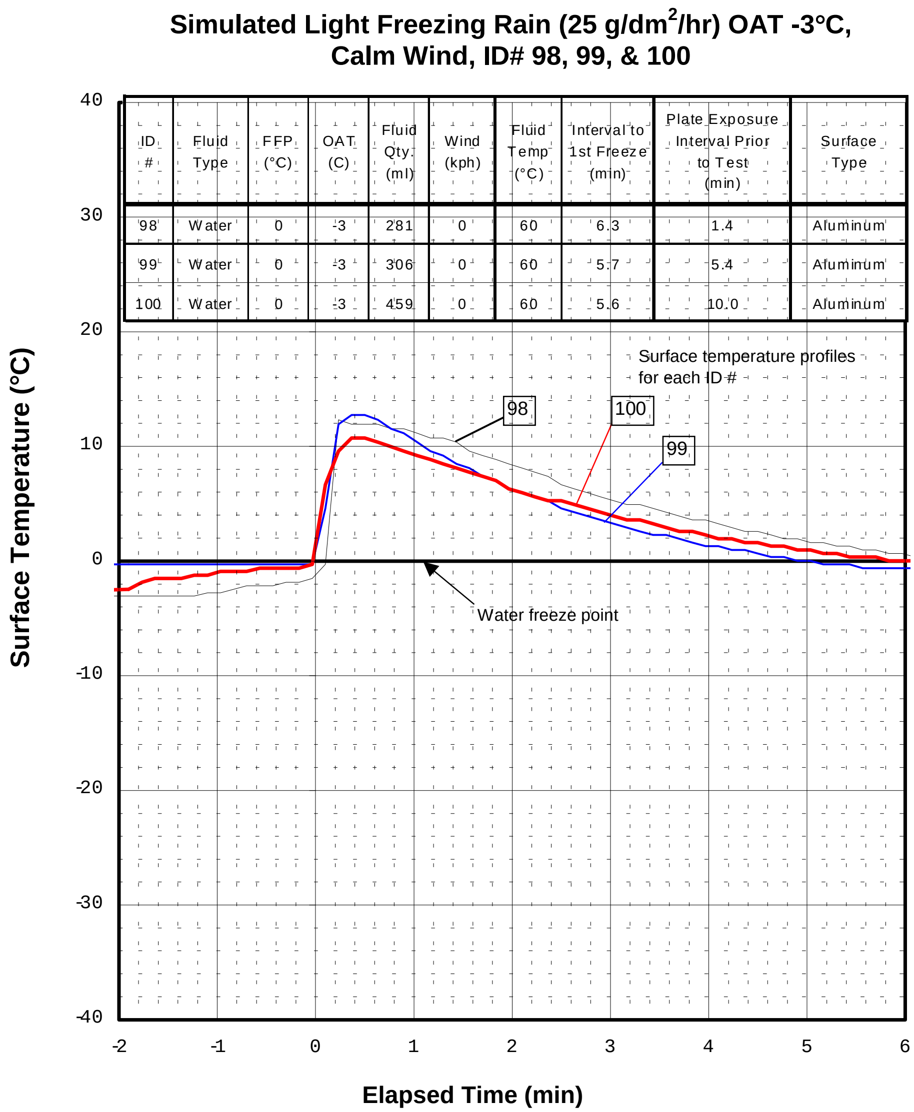
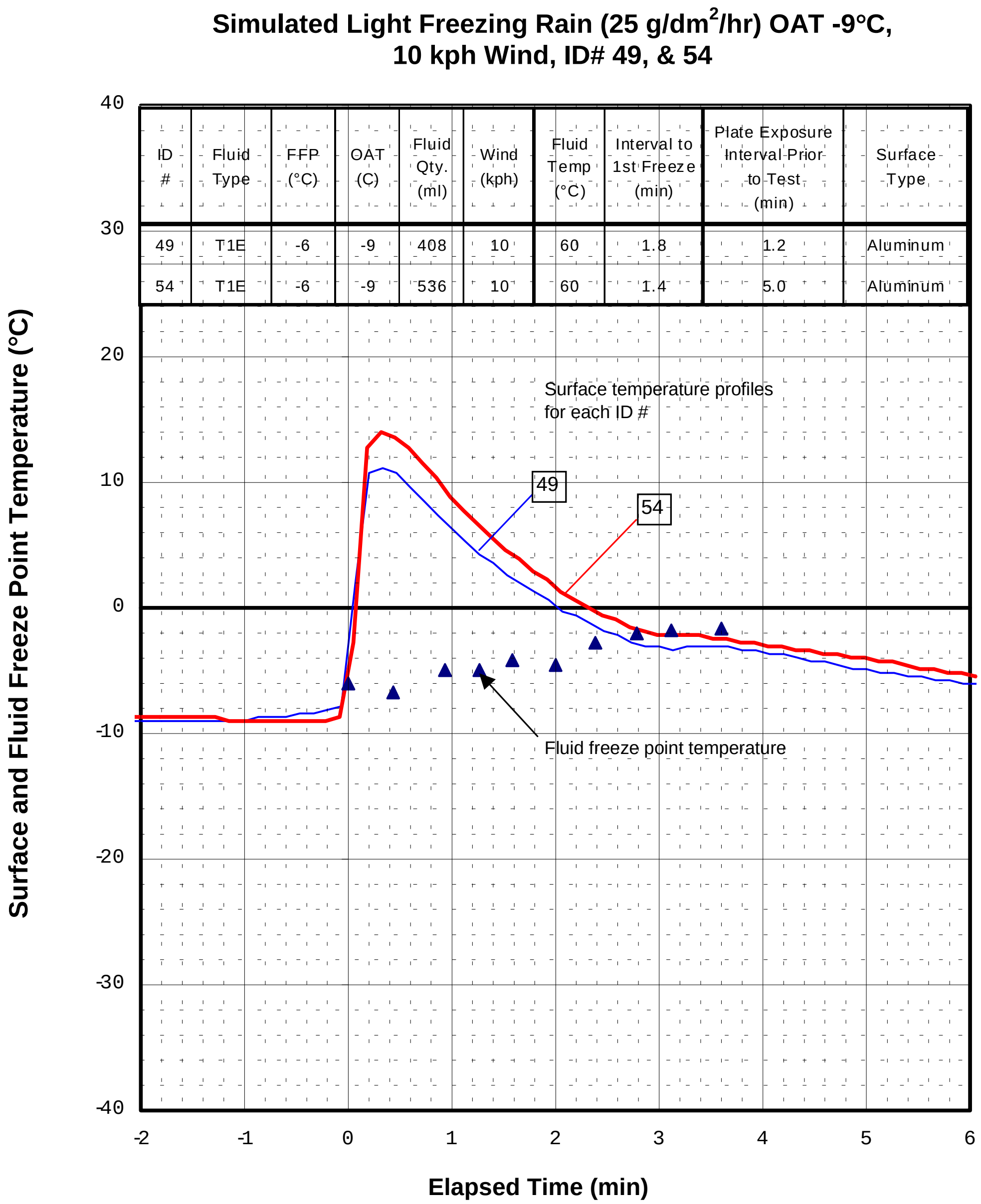



FIGURE 5-25. EFFECT OF AMOUNT OF CONTAMINANT – HOT WATER TRIALS

Tests reported in figure 5-25 were conducted with hot water, at an OAT of -3°C in a calm wind condition. Plate exposure times ranged from 1.4 minutes to 10 minutes. It can be seen that the corresponding elapsed times to freezing did vary as a function of the change in level of




| ID # | Fluid Type | FFP (°C) | OAT (C) | Fluid Qty. (ml) | Wind (kph) | Fluid Temp (°C) | Interval to 1st Freeze (min) | Plate Exposure Interval Prior to Test (min) | Surface Type |
|---|---|---|---|---|---|---|---|---|---|
| 49 | T1E | -6 | -9 | 408 | 10 | 60 | 1.8 | 1.2 | Aluminum |
| 54 | T1E | -6 | -9 | 536 | 10 | 60 | 1.4 | 5.0 | Aluminum |

FIGURE 5-26. EFFECT OF AMOUNT OF CONTAMINANT – TYPE I FLUID TRIALS

contamination, but to a minor degree. The fluid quantity however did show a strong correlation. Despite the differences in level of contamination, the plate temperature profiles were very similar. It is concluded that the additional fluid quantities needed to clean a heavily contaminated surface compensated for the heat lost in the ice removal process.

Figure 5-26 reports results from tests conducted with diluted Type I fluid at an OAT of -9°C with winds of 10 kph. The conclusions are similar with perhaps a slightly stronger correlation between the elapsed time and the duration of contamination interval.

Overall, it can be concluded that the amount of contamination on the surface does not exert a significant influence on elapsed time to freezing, under the test procedures followed in this study.

# 6. CONCLUSIONS.

Based on controlled laboratory tests, using 300 × 500 × 3.2 mm aluminum tests plates exposed to simulated freezing rain at a precipitation rate of 25 gm/cm²/hr, the following conclusions are made regarding fluid performance:

1. At an OAT of -3°C and wind speeds to 30 kph, hot water provided a period of protection of 3 minutes.

2. Hot water provides a period of protection equal to or better than Type I mixed to the approved buffer (-3°C) at an OAT down to -6°C and at wind speeds to 10 kph (2 to 3 minutes).

3. At the condition noted in CONCLUSION (2), a Type I premix provided approximately 2 to 3 minutes of protection.

4. At -9°C, with a 10 kph wind, Type I mixed to the approved buffer, performed slightly better than hot water.

5. There was more variability to the onset of freezing under calm conditions than under conditions of wind.

6. Wind increases the severity of the environment and reduces fluid performance.

7. Increasing the quantity of hot water delays the onset of freezing.

8. Hot water deicing at temperatures below -9°C is not considered a viable operational limit.

9. A 3-minute window before the onset of freezing, using hot water in quantities greater than what is required to deice, is attainable down to an OAT of -9°C with wind up to 10 kph on aluminum surfaces.

10. The level of surface contamination has no significant effect on fluid performance (increased quantities of hot water required to deice negates effect of increased contamination).

11. There was no significant difference in fluid performance between application of equal quantities of fluid by pouring and spraying during these laboratory studies.

12. Smaller quantities of fluid were required to deice painted composite surfaces than aluminum surfaces; similarly, the time to the onset of freezing was shorter for painted composite surfaces than for aluminum surfaces.

## 7. RECOMMENDATIONS.

Based on controlled laboratory tests, using 300 × 500 × 3.2 mm aluminum tests plates exposed to simulated freezing rain at a precipitation rate of 25 gm/cm²/hr, the following recommendations are made:

1. Conduct laboratory studies, under precipitation conditions, to establish a relationship between quantity of hot water applied and the onset of freezing for composite surfaces down to -9°C and wind speeds up to 10 kph; determine quantities of hot water required to attain a 3-minute window.

2. Conduct further studies outdoors, under precipitation conditions, on an operational aircraft and/or an aircraft wing to optimize hot water deicing technique to both maximize heat input and equalize heat distribution, taking into account the presence of composite surfaces.

3. Conduct further studies outdoors, under precipitation conditions, on an operational aircraft and/or an aircraft wing to determine the relationship between the quantity of applied hot water and the onset of freezing for aluminum and composite surfaces; determine quantities of hot water required to attain a 3-minute window.

## 8. REFERENCES.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2. Dawson, P., D'Avirro, J., *Hot Water De-Icing Trials for the 1994-95 Winter*, APS Aviation Inc., Montreal, December 1995, Transport Canada – Dryden Commission Implementation Project, TP 12653E, 48.

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## 9. GLOSSARY.

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|---|---|
| APS | APS Aviation Inc. |
| CEF | Climatic Engineering Facility |
| FAA | Federal Aviation Administration |
| FP | Freeze Point |
| FPD | Freezing Point Depression |
| NRC | National Research Council Canada |
| OAT | Outside Air Temperature |
| RVSI | Robotic Vision System Inc. |
| SAE | Society of Automotive Engineers |
| TDC | Transportation Development Centre |
| UCAR | Union Carbide Corporation |